DIGEST OF INDUSTRIAL AND TECHNICAL DEVELOPMENTS

Electronic Computers and Chemical Production

IN his article on "Computers for the Processing Chemical Data" published in our July issue (pp. 128-131) Lord Halsbury referred to a British chemical firm reputed to have no fewer than five electronic computers on order. We can now reveal that the firm is Imperial Chemical Industries. The machines involved are an Elliott 402, a Hollerith HEC 4, an Elliott 405, a Ferranti Pegasus and an I.B.M. 650; the last three computers will all have magnetic tape auxiliary storage facilities. The machines are to be installed in different parts of the company and are due for delivery in the next 6-12 months. All except the Elliott 402 are destined primarily for commercial purposes. This machine is to be engaged on scientific work, and the first problems to be put on to it will be the present routine load of mass spectrometer and kinetic calculations.

The Hollerith HEC 4 is to be used initially to take over the majority of the sales statistics work at present carried out by one of the company's conventional punched card installations. The Elliott 405 is being installed to handle as a first application the calculation of incentive bonus earnings, and the calculation and preparation of wages for a payroll of 7000. The Ferranti Pegasus is going to take over as a start much of the work connected with sales statistics and works cost of sales at present carried out by another of the company's punched card installations. The I.B.M. 650 in yet another part of the company will be used to handle work connected with the procurement and control of raw materials, and the costing of their conversion to finished products.

In addition, four electronic calculators have already been installed to further the work of some of the company's punched card installations. At this stage only the initial applications for the machines have been defined, but a considerable amount of exploratory work into other potential fields of application is being carried out. At this stage therefore the machines are to be regarded as being in the nature of research projects.

Shell has ordered another electronic computer, and this is to be installed at Stanlow. A Ferranti Mark I* has been working for some time in the Amsterdam laboratories of the Royal Dutch Shell group in Amsterdam, where it is used on plant design problems as well as for handling analytical data.

200 Films On Chemistry

MANY first-rate films about various aspects of the chemical and petroleum industries exist, and the Scientific Film Association (164, Shaftesbury Avenue, London, W.C.2) has just produced a catalogue listing details of 200 various films dealing with subjects in these fields. This is published as a special issue (June 1956) of *Scientific Film Review*. The list is classified according to the following main categories: general, ammonia, antibiotics, coal-gas, explosives, glass, insecticides, iron and steel, metals (non-ferrous), minerals, paper, petroleum, rubber and synthetics. The catalogue also includes particulars of a number of films on agriculture, atomic physics, crystallography, experimental chemistry and laboratory techniques.

Fuel Saving in Chemical Factories

THE chemical industry is taking a keener interest in fuel efficiency than ever before, according to the latest annual report of NIFES (National Industrial Fuel Efficiency Service). Of the heat and power surveys which NIFES made last year, 10.9% were concerned with chemical factories, as against 4.7% in the preceding year. NIFES estimates that the total fuel saving which would result from the implementation of its recommendations for these factories would be 12.4%, which is on the low side compared with what is possible in the iron and steel industry (26%) or in the manufacture of bricks, ceramics and cement (17.6%). The savings envisaged in these surveys are, of course, the savings which can be made on the operation of existing plant without substantial capital expenditure.

Fuel saving schemes financed under the Government Loan Scheme that was introduced in 1952 amounted to 126. The loans advanced added up to £436,000, and the total fuel saving that should materialise from these schemes is estimated at 31,600 tons of coal per annum. The average capital investment required to save one ton of coal per annum was therefore about £13.8.

238 oil conversion schemes were financed by loans totalling £1,048,000. In aggregate these will enable 201,500 tons of coal to be replaced by an equivalent amount of oil. The capital investment per annual ton of coal replaced is therefore £5.2.

Lithium from Gwelo

LITHIUM is one of the elements which has come prominently into the news because of developments in the nuclear energy field. One of the most important deposits of lithium ore is near Gwelo in S. Rhodesia. Last year over 85,000 tons of this ore were exported, and the capacity of the local processing industry has been trebled in recent months with the expansion of the £100,000 plant operated by Lithium Products Ltd. Other important materials mined in the vicinity are iron ore, coal and limestone. The Lancashire Steel Corporation is planning a £8-12 million expansion programme for the steelworks it is acquiring from the government. £2 million is to be spent on subsidiary projects, including the development of fertiliser production. The completion of the Kariba Dam will mean abundant electric power for the whole of S. Rhodesia, and this is bound to stimulate industrial development generally.

Fusion and Confusion

THE public relations side of the Atomic Energy Authority deserves to be congratulated for arranging a special preview of Calder Hall (which the Queen inaugurates on October 17) for the technical press, all too frequently ignored by the authority when it is releasing news. The AEA will certainly find that it pays good dividends to give the technical press an equal crack at a news story of technical importance, and we hope that its departure from past tradition opens up a new era in which the AEA will be more generous with technical information as opposed to news designed for popular consumption.

The preview was very well organised and was certainly a feather in the AEA cap. A far less happy affair was the press conference which the AEA held on the day it released its second annual report. It tried the patience of the representatives of the technical press, and we noticed that some daily papers which sent specialist reporters chose to ignore the report altogether in next day's editions. We gained the impression that without the press conference the report would have got a much better press! The conference started with a whole series of rather vapid questions about power from fusion reactions, and the answers were irritatingly vacuous and confusing. At present power from fusion holds only a limited interest for people outside the AEA, since very few folk have been allowed access to the classified data on fusion reactions. The report itself is vague on this subject. It contains the statement that the nuclear fuel (a mixture of deuterium and tritium) must be brought to a temperature in the region of one million degrees C to make a fusion reactor possible. Fusion could be initiated at much lower temperatures but it is not yet certain, says the report, that a pure fusion reactor can be built which yields more useful power than it consumes. Many methods have been tested for heating a gas under conditions of good thermal insulation, and very high temperatures have been achieved. The report stresses that this work is still at the experimental stage. It gives no indication either of the methods which have been tried nor of the temperatures which have been reached. It refers to the assistance which the AEA has had from university and industrial scientists, including experts on ionised gases, hydro-magnetics, shock waves and astrophysics.

The most remarkable fact about this press conference was the reluctance of all the AEA spokesmen to add one iota of information to that printed in the report. Most of the questions which the press asked failed to elicit any extra facts, which meant that the whole purpose of the press conference was defeated.

Bureaucratic Buck-passing?

ONE question asked at this conference was of more than ordinary interest. The reply which the journalist received was to the effect that the answer to his question should come from the industrial firm making the particular piece of equipment he was inquiring about. This raises a fundamental issue. It is common exeprience to take a question to the AEA and to be told that only the particular industrial firm involved can give a detailed answer. But when one approaches the firm one is told that nothing can be said without AEA approval and that it would be best to take the inquiry back to the AEA. That way many questions about industrial aspects of atomic energy get kicked about until they are lost, and this applies in many cases where no security considerations whatsoever arise. This mechanism is thoroughly unsatisfactory, and it comes dangerously close to the kind of buck-passing favoured by those bureaucrats who believe that 'knowledge is power' and that they gain in relative stature by keeping other people as ignorant as possible about the facts they manipulate.

We ourselves tried—without success—to get some enlightenment from Sir Edwin Plowden who presided over this conference about the ill-fated N.Z. heavy-water project. The report states that the original estimate for this project was £2 million, but this figure was later found to be less than half of the probable cost. Sir Edwin Plowden put all the blame for the miscalculation on the firm concerned, but surely the AEA must take *some* responsibility for estimates that are so far wide of the mark. It was quite evident that Plowden's answers to a series of questions on this matter failed to satisfy the press conference. Incidentally, the Risley representative was at pains to dissociate the Industrial Group from the whole heavy water affair.

Exploitation of AEA Inventions

TECHNICAL people will not find the report (which is published by HMSO, price 2s. 6d.) very informative, though it probably fulfils its primary function of indicating to Parliament the kind of work on which the AEA spent its vote of £54 million. Practically no statistics can be found in the report. For example, no statement is made about tonnages of uranium ore procurement, whereas the U.S. Atomic Energy Commission does not treat such figures as secrets. The AEA says that the uranium extraction process it to be changed to use magnesium instead of calcium for reducing the uranium hexafluoride. This will lead to big savings in raw material costs. Continuous operation is planned to replace batch working for other sections of the process. Also mentioned is the production of thorium in a factory operated by an unspecified firm acting as an agent for the AEA. Methods of adapting this process for large-scale production are under consideration. A small pilot plant has been separating fissile U233, fertile thorium and fission products from thorium irradiated with neutrons. Sufficient U233 has been prepared to make it possible to establish its key nuclear characteristics. Beryllium is also being made on pilot plant scale. A new class of alloys—Aereal alloys—is being developed for use in water-cooled reactor systems. These aluminium alloys (which contain iron, nickel, silicon or titanium) resist corrosion in water at high temperature and pressure.

The AEA staff increased about 20% in the year ending March 1956—to 23,973. The difficulty of recruiting engineers continues, which is not surprising as industrial firms are now competing for expert technologists in this field. A considerable number of AEA inventions are now available for exploitation by industrial firms. The report states that already 22 non-exclusive licences have been granted to U.K. firms to work such inventions, and about half a dozen to foreign firms (American, German and French). Inquiries about licences should be addressed to: The Patents Exploitation Officer, Patents Branch, U.K.A.E.A., Bedford Chambers, Covent Garden, London, W.C.2. Recently Mr. Thomas Benson Gyles was appointed to act as a liaison officer to advise industrial firms on the uses to which AEA inventions might be applied.

Synthetic Rubber

PRODUCTION of synthetic rubber in the United States will soon match the total world output of natural rubber. In 1955 private firms bought most of the $700 million industry from the U.S. Government, and they have expanded production considerably. By 1958 the capacity of the synthetic rubber plants will have increased by 40% and will amount to almost 1,720,000 tons; the production of

the world's rubber plantations is relatively stable at around 1,800,000 tons.

The International Synthetic Rubber Co., which four rubber companies have formed to produce general-purpose synthetic rubber in Britain, has now appointed its general manager. He is Mr. Donald A. Bennett. Aged 35, he was previously works manager of the plastics group of factories belonging to the Distillers Co. His industrial career started with British Drug Houses, after which he went to British Resin Products. From 1943 to 1946 he was on the research and development side of the Distillers Co. and then spent some time in the U.S.A. attached to the Goodrich Chemical Co. in Cleveland. He became plant manager of British Geon Ltd. in 1948, and later joined the Distillers executive committee responsible for plastics.

New Contracts

G. & J. Weir Ltd.. the Glasgow engineers, have now received the order for a fifth set of sea-water evaporating and distilling equipment to add to the £1¼ million order they received last February. The original order was for four sextuple-effect plants to produce 8000 tons of fresh water a day in the island of Aruba, Netherlands Antilles. It has now been decided to increase the capacity of the plant to 10,000 tons a day, bringing the value of this order up to nearly £1,500,000.

Simon-Carves have received contracts amounting to about £4½ million from the Steel Company of Wales for new coke oven construction in connection with the new £48 million development programme at the Margam steelworks. Two existing batteries of 90 coke ovens are to be extended by the addition of 25 new ovens, and a complete new battery of 80 ovens will be built on a new adjacent site. When the new construction is finished there will be a total of 310 post-war coke ovens at Margam all of them built by Simon-Carves.

Birwelco Ltd. are to supply four Petro-Chem Iso-Flow Furnaces for use in U.O.P. platforming facilities being engineered by Procon (Great Britain) Ltd. for The Trinidad Oil Co. Ltd. at their refinery at Pointe à Pierre in Trinidad, B.W.I. All of these heaters are of the radiant integral convection type. Their throughput varies from 238,200 down to 87,000 lb per hour.

Humphreys & Glasgow Ltd. have been awarded two contracts by the East Midlands Gas Board to build catalytic oil gasification plant utilising the Onia-Gegi regenerative process. At Meadow Hall gasworks, Sheffield, two units will be erected adjacent to existing water gas plant, each unit having a daily capacity of five million cubic feet of town gas. At Northampton gasworks, two oil gasification units will be built on the site of an old retort house which is being demolished. Each unit will have a daily capacity of three million cubic feet of town gas. Both installations have been scheduled for operation in the autumn of 1957.

German v. British Exports

IF Britain is to meet German competition in world markets, she must pay special attention to improving her sales promotion abroad and she must not neglect any opportunities of obtaining new export business. These are among the salient conclusions reached in an important article on "West Germany's Rising Competition with British Exports" published in the *Board of Trade Journal* (28.7.56), reprints of which are obtainable from: The Librarian, B.O.T., Horse Guards Avenue, London, S.W.1. Another important conclusion is that Britain must invest more in the modernisation and expansion of industrial capacity. In the long run a competitive advantage will rest with the country which is most successful in preventing inflation, and which achieves the most rapid increase in efficiency and sales promotion, and advances in technology.

German exports have been expanding vigorously. In 1954 and 1955 the volume of total exports was greater by 24% and 42% respectively than it was in 1953. The corresponding percentage increase achieved by Britain in the 1953-55 period was 12%. Last year we exported goods equivalent to 17.5% of the gross national product, whereas the comparable figure for Germany was 18%.

For the period 1953-55 German trade with North America amounted to $114 million whereas British exports to that region accounted for $24 million. The percentage increases over that period were respectively 35% and 3%. German trade with Latin America increased in a similar way, and reached a total of $73 million as against Britain's $8 million. Only in Eastern Europe did our export business rise faster (percentagewise) than Germany's, though the total value of our exports to that region was still slightly below that of the German—$60 million compared with Germany's $67 million.

In 1955 German exports of chemicals were worth $680 million compared with $221 million in 1950. This increase should be considered against the general pattern of expanding exports, some idea of which can be gained from the following table which shows what happened in some of the main commodity groups.

Commodity Group	Value $ millions				German exports	U.K. exports
	1950	1953	1954	1955	Percentage change 1953-55	Percentage change 1953-55
Chemicals ..	221	477	605	680	+43	+31
Metals and metal manufactures ..	453	684	755	895	+31	+16
Mineral fuels ..	323	486	541	532	+ 9	− 4
Oils and fats ..	5	14	20	27	+93	+58
Machinery and vehicles	472	1673	2041	2457	+47	+15

Germany's share of world trade in chemicals has risen from 13.5% in 1951 to 17.4% in 1955. In this period the U.K. share has dropped from 17.3% to 16.7%. For the U.S.A. the corresponding figures are 30.8% and 28.3%.

The article stresses the fact that Germany has been devoting a higher proportion of her national income to industrial development than Britain. Gross fixed investment in Germany averaged 21% in the years 1950-54, as against 14% in the United Kingdom. The net fixed investment, which indicates the amount of capital accumulation, for the two countries was respectively 14% and 5½% of the net national product over the same period. Broadly, over the whole field of raw material and fuel costs, the U.K. enjoyed some small advantage. Coal and electricity were rather cheaper in Britain; hard coke was a little dearer. Fuel oil prices were about the same. Steel prices are lower in the U.K., in some cases by as much as 20%. Lead and zinc prices are probably about the same in the two countries; most other non-ferrous metals appear to be rather cheaper in the U.K.

A great many factors have to be considered when one attempts to figure out the reasons for Germany's success in building up her export business. One that must be remembered is that British income tax rates are more progressive than the German, so that taxation acts as a greater disincentive to the higher managerial and technological grades.

Restrictive Trading Agreements

AN important order, the first made under the Restrictive Trade Practices Act 1956, is due to come into force on November 30, 1956. During the three months following that date, particulars of the classes of agreement specified in the order must be furnished to the Registrar of Restrictive Trading Agreements at Chancery House, Chancery Lane, London, W.C.2.

The kinds of agreements to be registered and the dates of registration are set out in the *Registration of Restrictive Trading Agreements Order* 1956 (HMSO, price 3d.). Details of the way in which registration is to be carried out will be given in regulations to be made by the Registrar (Mr. R. L. Sich), and these will be issued before the Registration Order comes into operation. The regulations will also lay down the fees to be paid for inspecting the Register and for copies of, or extracts from, registered documents.

Chemical Engineering at Glasgow

IN last month's "Digest" we mentioned the creation of a chair of chemical engineering at the Royal Technical College, Glasgow. This comes within the Department of Mechanical, Civil and Chemical Engineering, which has been transferred to a new engineering block where greatly increased facilities for teaching and research are available.

The present chemical engineering course leading to the B.Sc. degree extends over four years. The first year comprises mathematics, physics and chemistry; the second year subjects are mathematics, applied thermodynamics, mechanics, electrical engineering and engineering drawing; in the third year, the engineering group subjects are continued, and organic and physical chemistry are introduced; the final year covers chemical engineering design, technical chemistry and advanced chemistry. The course, in common with all Glasgow engineering courses, operates on the sandwich system which allows the students to spend three summer periods in industry during their undergraduate training. The chemical engineers may spend these periods with chemical plant manufacturers, with maintenance or shift engineers in chemical works or oil refineries, and in chemical development laboratories or design offices. The summer period of the final year is spent at a Works Practice School at Ardeer or on a laboratory research project.

It will be seen that the engineering bias of the curriculum is more pronounced than in some chemical engineering courses, and it is in fact intended for the student whose natural bent is towards engineering. The alternative college course, which is also recognised by the Institution of Chemical Engineers, leads to the degree of B.Sc. in Applied Chemistry. This is predominately a chemical course, with lectures in applied thermodynamics, electrical engineering and engineering drawing in the second year. The final year is similar to that for chemical engineering except that chemical engineering design is replaced by a selected advanced chemistry course.

In addition to these two degree courses, the college offers courses leading to the Associateship of the College. The Associateship, like the degree, may be awarded with first or second class honours, and these awards are recognised as equivalent to an honours degree by Government Departments.

Dr. A. W. Scott, who has been appointed to the chair of chemical engineering, was formerly Associate Professor responsible for the chemical engineering courses in the College. He is the author of numerous papers on heat and mass transfer. During the last war he was seconded for Government service as engineering adviser on dehydration and has continued to act as honorary adviser since his return to College. Among the other research investigations under his direction is an extensive investigation of corrosion fatigue and its inhibition.

More Man-made Fibre

OUTPUT of man-made fibres in Britain rises steadily. According to the latest Board of Trade figures, production is 9% higher than it was a year ago. This is in line with the universal trend. World production of man-made fibres in 1955 was 5600 million lb, of which about 560 million was made from materials other than cellulose, i.e., the so-called synthetic man-made fibres such as nylon. This output is to be compared with a world total of man-made fibres in 1954 of 4900 million lb, of which about 390 million was synthetic.

Several new plants will add substantially to Britain's productive capacity. For example, the new Courtaulds plant at Grimsby, which is announced for completion during the current year, will add a capacity of 100 million lb of viscose staple fibre to the existing national capacity of about 250 million lb. The continuous filament yarns (which include viscose rayon, acetate rayon, nylon and Terylene) have currently a capacity of some 250 million lb. Thus the grand total of all man-made fibres made in the U.K. is comparable with the output of wool yarn, which is approximately 500 million lb. The cotton capacity is 1000 million lb. Of the continuous filament yarn produced in this country for use in clothing approximately 40% is acetate rayon.

Nylon capacity was increased in 1954 from 10 million lb by expansion at the Pontypool works of British Nylon Spinners Ltd. The increase was to 25 million lb. The Pontypool expansion was substantially completed in 1955. British Nylon Spinners are installing new facilities at Doncaster on a site which previously belonged to British Bemberg. Production began early last summer, but full operation is not expected until about the end of 1957. The planned production has not yet been stated, but it will probably raise the output to some 45 million lb.

In the nylon field British Celanese Ltd. have announced that they have obtained from British Nylon Spinners Ltd. a non-exclusive licence for the manufacture of nylon-6, which is polycaprolactam and differs from the better-known nylon-66, which is polyhexamethyleneadipamide.

Progress in the production of Terylene (polyethylene terephthalate) continues. The output in 1954 totalled two million lb from pilot plants. In 1955 the new Wilton plant commenced with a capacity of 11 million lb, and this output will be doubled when present construction is completed. Further plans are in hand to raise the output to 44 million lb.

A new development is the £3½ million plant to be erected by the Chemstrand Company in Northern Ireland for the manufacture of fibres from polyacrylonitrile. This material has been very successful in the U.S.A. for the knitted goods trade, and American plant capacity is approaching that for the manufacture of nylon. New plants have based their manufacture of monomer on hydrogen cyanide and acetylene, and they show promise of making a fibre cheaper than either nylon or polyester. Courtaulds are running a pilot plant and have a production unit under construction which should be producing next year

BCE 299 for further information

Victoria Instruments

DEWPOINTMETER

Developed by British Coal Utilisation Research Association

SPECIFICATION:

The instrument consists essentially of a high quality Pyrex glass detector element bearing 2 Pt / Pt 13% Rh thermocouples in the hemispherical surface, and mounted on a probe 1 inch in diameter and 6 ft. long. Cooling air and compensating leads from the other end of the probe connect to a box (24 in. x 10 in. x 6 in.) of good quality hardwood fitted with Rototherm, double range voltmeter and millivoltmeter and a 5 range microammeter. All these instruments are first grade accuracy (B.S.S. 89) having spring mounted movements and are built into a single unit which is internally earthed.

Cooling air connections are of the "Instantair" type and all metal parts are chromium plated. Calibrations can be made in English or Metric units.

Overall weight—

Probe and leads	...	8 lb. (4 Kg.)
Box	...	30 lb. (14 Kg.)

BRIEFLY, the Instrument:

The probe is inserted into the gases under test and the detector element temperature is controlled by the admission of cooling air from some suitable source (e.g. a small compressor) to its underside. The two thermocouples measure this temperature. When the surface is cooled below the dewpoint of gases they also become the electrodes of a "cell", the conductivity of which is recorded on the microammeter.

The detector element is constructed in such a way that its temperature can be controlled at fixed temperatures below the dewpoint for long periods, and comparative measures of the amounts of sulphuric acid condensed out at any selected temperature can be made.

The instrument is of particular value in determining the temperature range over which corrosion by sulphuric acid may be expected.

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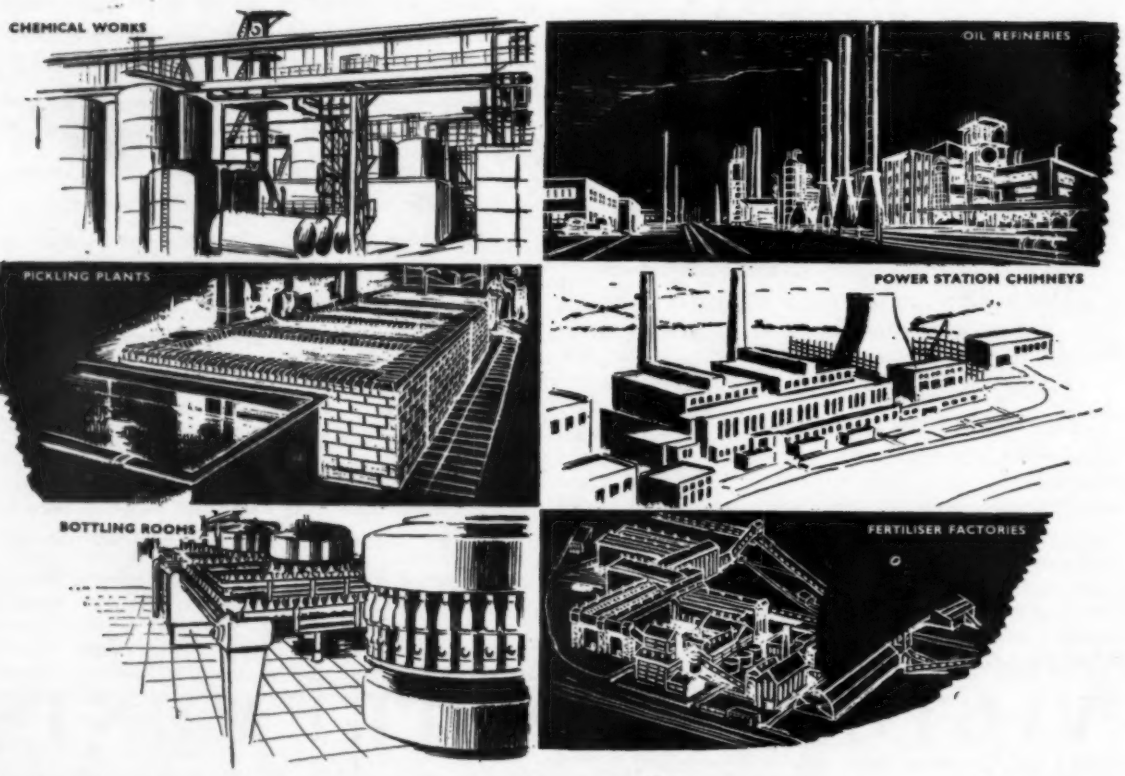

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dm HW. 23

BRITISH CHEMICAL ENGINEERING
A HEYWOOD TECHNICAL PUBLICATION

What Price a Few Fish?

THE gravity of the whole problem of river pollution has been impressed upon the public by the judge who ordered Monsanto Chemicals to pay £14,000 damages for discharging effluent into the River Dee. Of the seriousness of this problem and its equally ugly sister—atmospheric pollution—most chemical firms in Britain are fully aware. They realise that it is criminal to treat rivers as though they were open sewers, and they are prepared to meet their full social and legal responsibilities in this connection.

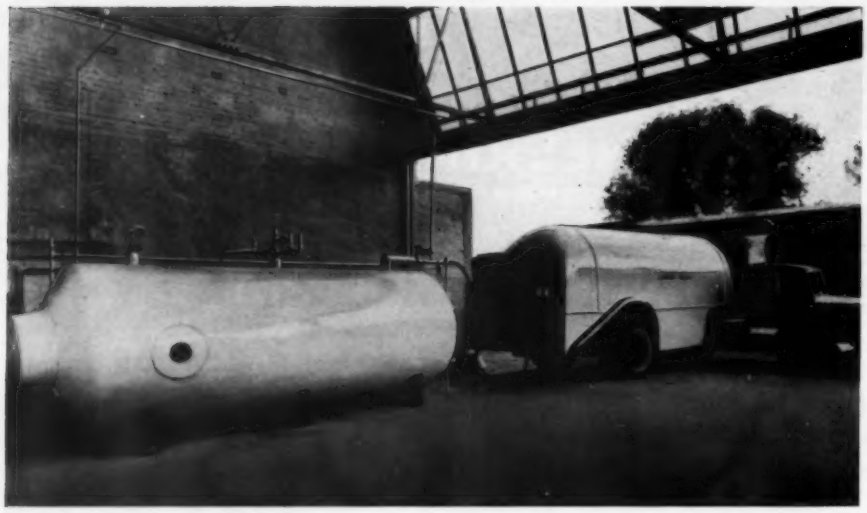
The technical difficulties of treating industrial effluents and rendering them harmless are considerable, and the industrialists who fulfil their duties conscientiously find that it is an expensive business. Sir Miles Thomas has stated that Monsanto has spent a million pounds on its effluent problem and continues to spend at the rate of £75,000 a year. This was a point worth making in view of what had happened to the River Dee, and we applaud Sir Miles's statement on this matter. But we cannot congratulate him on the further remarks which he made on this occasion, when he said that the fate of a few sporting fish could not be compared with the interests and livelihood of 2000 Monsanto employees. That is an entirely wrong approach. It is the *pollution* that is the evil, the disease of industry, so to speak, against which the Rivers Pollution Act is aimed. The death of the fish in the River Dee was merely a symptom of that evil, and there can be no hope of curing the disease unless one is prepared to take notice of the symptoms and act accordingly. It needs to be remembered that when fish begin to die it may not be long before all the rest of the life in a river is destroyed. A dead river is an abomination, even if it is judged by the lowest materialistic standards, and will not be tolerated by any civilised society. At this stage in history an industrialist who knowingly poisons a river and takes no steps to correct the abuse breaks the law in a big way and can expect to be brought to justice.

Water pollution must be taken far more seriously than it has been taken during the last century. We are now entering the Atomic Age, which means that we are beginning to produce radioactive wastes on an ever-expanding scale. The potential damage that could be caused by inefficient disposal of those wastes would be enormous. Indeed it has been estimated that all the oceans of the world could be poisoned inside fifty years if urgent and adequate steps are not taken to control the disposal of all atomic "sewage." Britain can well be proud that the record of her atomic plants in this context has been very good indeed, but the experts of our Atomic Energy Authority would be the first to admit that the problem will become more difficult as the years go by and fission products in ever-increasing quantities are produced in nuclear reactors. A new order of toxicity is inseparable from the effluents, both water-borne and air-borne, of the Atomic Age, and standards of effluent treatment must accordingly be raised. Almost certainly new tricks will be devised to render atomic effluents harmless, and some of them should prove applicable in other industrial fields, which should lead to the more efficient handling of conventional effluents.

In the field of air-borne effluent disposal, the advances on the industrial atomic front have necessitated closer investigation of the key phenomena involved and a good deal of valuable data has been collected and applied. The stack problem, for example, is now far better understood than it was ten years ago, and it is no accident that the best book dealing with the fundamental aspects of this problem is one which was prepared under the aegis of an atomic energy authority (the U.S.A.E.C.), namely *Meteorology and Atomic Energy*, which we mentioned in last month's "Digest." The facts that have been collected have been effectively applied by the engineers responsible for Windscale and similar atomic plants, and doubtless in due course they will be widely applied to the solution of the air-borne effluent problems which arise in more conventional factories. The Beaver Report has made it clear how much remains to be done before Britain's skies can be cleared of atmospheric pollution.

To turn from radiochemicals to detergents may seem like going from the sublime to the ridiculous, for detergents seem such very harmless substances compared with, say, fission products. Yet these compounds which are such a boon to the housewife have proved unmanageable after leaving the kitchen sink. They demonstrate that so far as effluents are concerned there is only one sure maxim: it is better to be safe than sorry. The recent report of the Jephcott committee tells the story of what these chemicals are doing to sewage farms and rivers all over Britain. It was noticed some time ago that the widespread use of detergents was causing foam to appear at most of the activated sludge plants in Britain, and it soon became clear that the efficiency of the biological oxidation process was dropping off. The net effect was that some detergent went straight through the sewage farm without being decomposed, and this caused foaming in the rivers into which the treated sewage was discharged. Factories using the treated liquor for cooling purposes found that it frothed abundantly; great balls of foam broke off from vents, and rolled around the works like so much tumble weed.

The Jephcott committee says that the situation is getting worse, and the majority view is that the Government may soon have to control by law the range of detergent chemicals which can be sold. We believe that the Jephcott committee was fully justified in taking a serious view of the damage being done by detergents, which, however, have so far killed no fish, according to the experts. Surely those chemical effluents which kill sporting fish (the trout is virtually the legal "standard" in water pollution cases) should be considered even more seriously: they should not be allowed to ruin our rivers, from which so much of our drinking water is taken.



A 4-ton liquid carbon dioxide tanker filling a 5½ ton storage tank. (Courtesy, the Carbon Dioxide Company.)

THE TRANSPORT & HANDLING

by D. H. EASTLAND, Ph.D., D.I.C., A.C.G.I.*

The techniques and equipment involved in the transport and handling of liquefied gases have made rapid strides in the last few years, and this article describes some of the more recent innovations in this field

THE technology connected with the use of liquefied gases has made considerable advances since the early experiments were carried out in the nineteenth century and the first decades of this century. Many of the principles which are applied have remained the same throughout, an example being the use of pressure and vacuum insulation to maintain gases in the liquid state. Although in the majority of cases the liquids are eventually used in the gaseous form, volume considerations and in particular the value of bulk density affect the economics of transport and storage. This factor has an important bearing on the mode of handling. Table 1 gives a few of the physical properties of some liquefied gases.

It can be seen that the bulk density of the gases makes it impractical to transport them at 1 atmosphere pressure but this volume can be decreased by the application of pressure. When handling small amounts, commercial practice in the U.K. is to employ high pressure cylinders into which the gas is filled. Some of the usual pressures are given in Table 2.

In the case of gases which have critical temperatures above room temperature, the application of pressure in excess of their equilibrium vapour pressures will result in liquefaction, and hence it is possible to obtain both gas and liquid from these cylinders. This point is sometimes important to remember when high gas flows are required from a cylinder, as the maximum rate of gas withdrawal is governed by the rate at which heat can enter the cylinder and vaporise the gas. For higher rates it is necessary to employ a dip pipe in the cylinder and an independent vaporiser. An example of this application is the use of chlorine for treating cooling water where chlorinators are designed to handle either liquid or gaseous chlorine.

The storage under pressure of gases whose critical temperatures are below ambient temperature involves the use of strong high pressure cylinders of considerable weight. The ratio between the weight of cylinder and weight of gas is between 10 and 12 for oxygen in normal commercial cylinders, and hence the weight of the cylinder represents a considerable penalty in freight charges and also in the ease of handling. Although not commercial practice, it is possible by the use of higher pressures and special alloys to reduce this ratio; for example, the figure was brought down to 3.38 for the cylinders used by the Hunt expedition which climbed Everest, and a ratio of about 2 is possible with resin-impregnated fibreglass spherical containers. However, the bulk density of gas and container is still high, and it is better to transport the gas in liquefied form over long distances, especially if the scale of operation is large.

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Handling of Liquefied Gases

Most liquefied gases are non-corrosive to steel in the absence of moisture, so this metal is satisfactory as a material of construction at ordinary temperatures. Below −40°C low temperature embrittlement occurs, and steels with an Izod impact figure of below 25 ft lb. at their lowest working temperature are not recommended. Austenitic stainless steels and non-ferrous metals such as copper and aluminium and some of their alloys do not suffer from this disadvantage and often show improved tensile and ductile properties at the lower temperatures.

Although more expensive they find extensive use in the manufacture of equipment for handling the lower boiling point gases. Liquefied gases do not generally possess unusual physical properties different from normal liquids. They will flow under gravity and can be pumped, but care must be taken in these operations to prevent them boiling and causing gas locking. The normal procedure is to maintain the pressure in the system above the vapour pressure corresponding to the temperature of the liquid. For low rates of flow and small heads (e.g. decanting the liquid from one vessel to another) it is convenient to use the pressure generated by vaporising part of the liquid in heat exchange with the atmosphere.

Fig. 1 shows a storage tank which is emptied by means of a pressure raising coil. Liquid is introduced into the coil below the tank by gravity feed, and the gas produced is returned to the tank above the liquid level. The pressure inside the tank is thereby raised to a value depending on the design of the tank and its safe working pressure. On opening the main valve, liquid flows up the dip pipe and is discharged. For higher flows and pressures a pump is installed as close as possible to the tank and fed from a bottom take-off. The design of this suction is important, as the pressure drops due to valves or restrictions will lower the pressure in the liquid to below saturation and cause boiling. The gas thus formed will find its way to the inlet of the pump and will lead to inefficiency in the case of a reciprocating pump and loss of prime with a centrifugal. Modern practice is to apply pressure to the liquid on the inlet side so that it is "undercooled" below the saturated temperature corresponding to lowest suction pressure at inlet to the pump.

Some rotary pumps of recent design[1] employ an auxiliary method of increasing the pressure at the inlet to avoid cavitation. A "screw booster" is fitted on to the main shaft and consists of a helical propeller which protrudes into the inlet pipe. Gas and liquid entering the pump are therefore given an initial compression, which tends to recondense the gas and only liquid is fed to the impeller. An alternative method where a source of refrigeration is available at a suitable temperature is to sub-cool the liquid so that any heat inleak is taken up as sensible heat by the liquid.

OF LIQUEFIED GASES

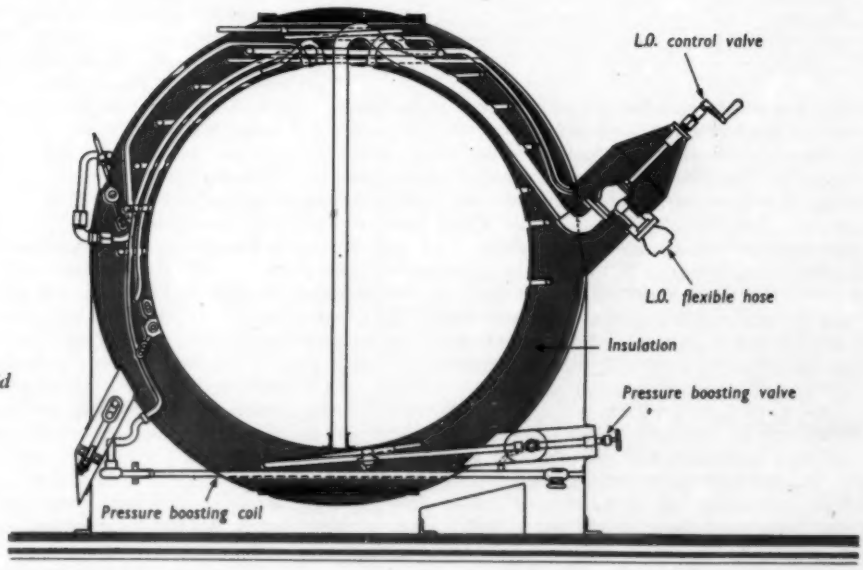


Fig. 1. Cross-section of liquid oxygen tank.

Evaporation Losses

In the storage of gases at temperatures below ambient the chief factor in the design of the vessel is to keep the heat inleak to the contents as low as possible. The gas lost by vaporisation due to this heat transfer from the atmosphere represents the inefficiency of storage of liquefied gases and any improvements which can be effected in reducing the heat inleak is a financial incentive especially if the stored material is valuable. Where there are facilities for collecting the gas, for example in gas holders for subsequent use or recompression, the losses from the storage tanks are not relatively so important so long as there is a

Table 1. Properties of Commercial Liquefied Gases

	°C B.P. 1 atma	Critical Temp. °C	Critical Pressure atma	Volume of 1 cu. ft liquid evaporated to 1 atma & 21° C
Ammonia	−33	132	112	950
Chlorine	−35	144	76	520
Propane	−42	97	42	315
Carbon dioxide	−79	31	73	—
Acetylene	−84	36	62	—
Methane	−161	−83	46	635
Oxygen	−183	−119	50	860
Nitrogen	−196	−147	34	695
Hydrogen	−253	−240	13	855
Helium	−269	−268	2.3	755

Table 2. Normal Cylinder Pressure of Gases

	Critical Temp. °C	Compression Pressure atm.
Ammonia	132	4-8
Chlorine	144	3-6
Propane	96	5-10
Carbon dioxide	31	30-55
Acetylene	36	15*
Methane	−83	
Oxygen	−119	132
Nitrogen	−147	132
Hydrogen	−240	132
Helium	−268	132

**in acetone*

steady demand for the gas. A further source of inefficiency occurs in transfer operations and gas is generated in cooling down the associated equipment to the temperature of the liquid. The amount of loss depends largely on the materials of construction and their thickness, and a warm tank will give a greater loss than one which has been in operation and is therefore "cold." As an example, 1 lb. of copper requires 0.30 lb. of liquid oxygen to cool from ambient, whereas 1 lb. of aluminium requires 0.67 lb. of liquid oxygen. A further "flash" loss will occur if the liquid is initially at a higher saturation pressure than that of the container into which it is being transferred.

Insulation

Fibrous materials such as slag wool and powdered materials such as magnesium carbonate have found considerable use for the insulation of gases obtained by liquefaction of air, whereas cellular materials such as cork are employed for liquid chlorine, carbon dioxide and ammonia where the temperatures are not so extreme. Recently there have been considerable advances in the manufacture of lightweight insulants from expanded plastics such as P.V.C., polysters, and ebonite, but in all cases the question of inflammability must be considered, especially if liquid oxygen is present.

Modern practice is to utilise vacuum powder insulation, especially for low temperatures. The advantages of vacuum powder insulation can be seen by reference to Fig. 2. The experimental curves are plotted showing the evaporation losses from a 5-gallon copper dewar containing liquid oxygen. In one series the losses were measured at different vacuum with the interspace between the two walls containing air whereas in the second series the interspace was filled with Santocel D. powder. It can be seen that for all values of vacuum except the very lowest, vacuum powder insulation shows a distinct advantage over straightforward evacuation. The generally accepted explanation[2] is that for an interspace filled with gas at atmospheric pressure the majority of the heat transfer takes place by convection. On reducing the pressure the thermal conductivity of the gas remains almost constant but the convection is appreciably reduced. A flattening out of the curve occurs when the geometry of the interspace and the pressures are such that the mean free path of the molecules approaches the distance between the hot and cold walls. Convection has been eliminated at this point and heat transfer is by conduction and radiation only. Further reduction in pressure decreases the number of molecules present and the conductivity therefore falls, as is shown on the curve, until a final steady value is obtained which represents the heat transfer by radiation. Analogous behaviour occurs when the interspace is filled with powder. In this instance the transitional pressure occurs when the mean free path equals the interstitial distance between the particles of powder. With finely divided powders the interstitial distance is extremely small and therefore the transitional pressure is relatively higher. Owing to the microcellular structure of Santocel or silica aerogel this value can exceed 1 atmosphere so it is found that this powder has a lower apparent thermal conductivity than still air. Other points to be noted are that the value of the transitional pressure is independent of the size of the vessel and radiation heat transfer is largely eliminated except in special cases, in particular where the thickness of powder is not great. It is therefore not necessary to resort to highly polished surfaces as is the case in ordinary vacuum insulation.

Vacuum powder insulation has distinct advantages when considering the mechanical design of storage vessels. By introducing powder into the vacuum space a high insulating efficiency can be obtained without resorting to the very low vacuum which would be required for a similar efficiency without powder. Thus the choice of vacuum pumps and the tolerance of leaks is considerably simplified. For example, for a vessel of average size where the inter-wall distance is between 2-12 in. the pressure at which the conductivity is 10% of its normal value is 10^{-4} to 10^{-5} mm.Hg. With interspace filled with slagwool this pressure rises to .01 mm.Hg. and with a fine powder such as basic magnesium carbonate the corresponding figure is 1 mm. For very small containers there is no need to use powder insulation as very hard vacuum can be quickly applied and the vacuum space sealed. At these low values the conduction through the powder is often greater than the radiation between the walls and hence there is no advantage to be gained. For large vessels whose construction involves an appreciable amount of welding, the vacuum powder technique is generally accepted practice. Such a method also possesses the safeguard that if vacuum failure should occur there is some measure of insulation afforded by the powder alone. Vacuum insulated tanks operate in the range of 10-1000 microns and need pumping down from time to time. Certain difficulties do exist such as filling the vessel with powder and degassing of the powder but techniques are being evolved to overcome them.[3] A typical pumping layout is shown in Fig. 3.

Pipelines can cause an appreciable amount of evaporation especially if deterioration occurs in the lagging due to ingress of moisture. Increasing the thickness of lagging does not give a corresponding improvement in heat insulation especially with small diameter pipes. Extra lagging often increases the over-all losses by evaporation as there is more material to cool down. This factor applies particularly if the line is in intermittent operation. Vacuum insulated pipelines are finding increasing use especially

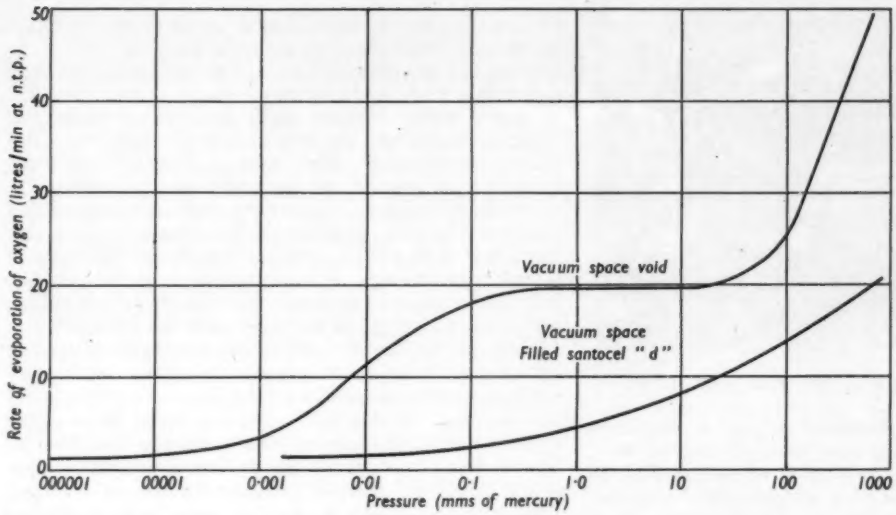


Fig. 2. Graph illustrating the difference between heat transfer in an insulated container with and without powder filling. It shows the rate of evaporation of liquid oxygen from a 5-gallon copper Dewar vessel in litres of dry gas at N.T.P. per minute versus pressure in the evacuated space.

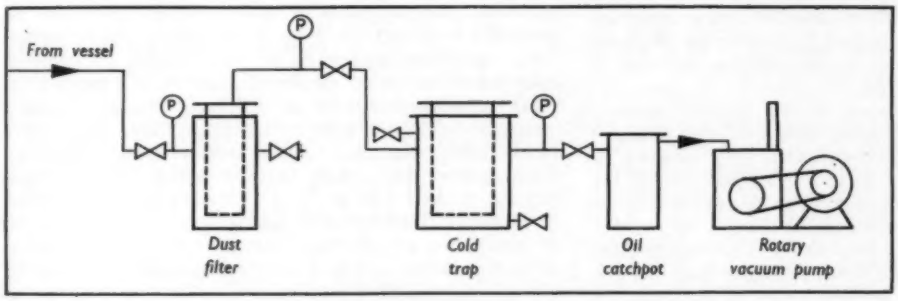


Fig. 3. Typical pumping arrangement for evacuation vacuum powder insulated equipment.

where there is a permanent flow of liquid—for example between a liquefying plant and storage tanks. By employing suitable alloys such as nickel-iron which possess low coefficients of expansion temperature stresses can be kept sufficiently low to enable them to be taken with safety by the metal. Heat inleak at supports can be reduced by lengthening the path of conduction by using configurations such as cones.

Transport of Liquefied Gases

The transport of liquefied gases involves the use of a wide range of containers. Cylinders and drums designed for pressure working are generally used for liquid with boiling points in the upper range, e.g. chlorine, ammonia and the more volatile petroleum fractions such as butane and propane. The contents are kept at atmospheric temperatures and the pressure so generated contained by the vessel. Where bulk supplies are to be transported resort is made to road and rail tankers. A considerable amount of liquid chlorine is shipped by these two methods, road tankers of either 7 or 10 tons capacity or rail wagons of 14 tons capacity being employed in this country. Rail wagons sometimes employ a thin layer of insulating material round the container to keep the pressure down. In order to accelerate the emptying and filling of these tankers dry compressed air is utilised. On road tankers a small compressor is therefore built on to the chassis and driven from a power take-off from the engine of the vehicle.

The handling of carbon dioxide has received close attention in this country since the war. A large amount of carbon dioxide is shipped in the solid form, especially when it is used as a refrigerant. Where bulk quantities are required, for example in the beverage industry, this method of supply involves a lot of handling and also necessitates the use of converters for reconverting the solid into liquid with its attendant losses. Liquid carbon dioxide can be supplied in cylinder form but such a method also involves handling difficulties and weight penalties. Liquid carbon dioxide can now be supplied in this country by road tankers specially designed to transport four tons of the liquid at low pressure, as illustrated on p. 244.

The liquid is pumped into cork insulated storage tanks of 1½ or 5½ tons capacity, two hoses being employed for the transfer operation, one for liquid and the other to equalise pressure in the gas spaces in both tanks. Filling rates of the order of 200 lb. per minute are achieved without interrupting the normal working of the storage tank. During storage the carbon dioxide is kept at between 240-280 lb./sq. in. pressure by the use of a condensing coil fitted into the tank and operating with a small Freon refrigeration unit. In larger installations the gas produced by evaporation is often collected, compressed, and reliquefied and then returned to the tank.

Further down the temperature scale the transport of liquefied gases such as oxygen and nitrogen has increased considerably during the last few years. With these gases little or no pressure is applied other than atmospheric and resort is made to efficient insulation as described in a previous section. In the United Kingdom road transport plays an important role in the delivery of liquid oxygen both to consumers and between depots. The early design of tanker incorporates a spherical container similar to the static storage tanks and fitted on to a suitable lorry. These tanks generally hold in the order of 105,000 cu. ft of liquid oxygen.

To enable the number of journeys to be reduced larger

Fig. 4. A modern liquid oxygen road transporter.

tankers such as the one illustrated in Fig. 4 have been designed but road transport regulations, especially those relating to the width of a vehicle, have necessitated the change to a cylindrical form, a disadvantage being that this shape is not so efficient for keeping heat inleak to a minimum. Where long hauls are involved, as in America, vacuum powder insulation is used to keep down the losses and road vehicles with up to 460,000 cu. ft capacity employed. The larger types of vehicle are generally articulated trailers. Depending on the locality there is generally a break-point between road and rail transport and in the U.S.A. vacuum-insulated rail tankers of capacities of 750,000 cu. ft and 1 million cu. ft are employed. Vacuum pumping equipment is installed at the filling depot and the vacuum space of the rail car pumped down each time it returns to the depot. The storage tanks to supply these vehicles are naturally larger than those in this country of which 2 million cu. ft is a usual size. Designs have been erected in sizes up to 75 million cu. ft capacity and the materials of construction have varied from stainless steel to prestressed concrete.[4] The larger tanks have departed from the spherical shape and are generally vertical ellipsoids or vertical cylinders with flat bottoms. With the larger tankers transfer of liquid is usually performed by pumping in order to get a quicker turn-round time.

The scope of road transport is governed by the nature of the area and in particular by the average speed that a vehicle can maintain. British regulations which restrict the speed to 20 m.p.h. of all lorries of unladen weight in excess of 3 tons are more severe than in other countries where faster speeds are permitted. With all tankers care must be taken to avoid excessive movement of the liquid during transit. Apart from affecting road-holding qualities the splashing of liquid increases its evaporation rate. Careful design of baffling is required to keep this as low as possible but nevertheless the losses in transit are generally higher than when the tank is stationary.

One of the most recent advances in the dispensing of liquid oxygen is the use of a mobile cylinder filling unit. This unit consists of a lorry with a liquid oxygen storage tank, a high pressure pump and a source of heat for vaporising the liquid oxygen. Such a vehicle is sufficiently versatile to be able to dispense liquid oxygen to consumers who have their own evaporator which can be operated to suit their own demand rate and also to fill cylinders with high-pressure gas where the consumption is lower, say below 35,000 cu. ft per week, and the installation of cylinders is satisfactory to cover requirements of gas. In earlier models heat was extracted from the atmosphere, but by reason of the low heat transfer rates on the air side the equipment tended to become too bulky when higher rates of flow were required. Heat is therefore supplied by heat exchange with the cooling water and exhaust gases from the engine which is being run to operate the high-pressure pump, or alternatively by an independent oil-fired vaporiser. The advantage of such a vehicle apart from its versatility is the service value it can give to the customer.

An interesting application in the handling of liquefied gases which has been developed since 1942 is the use of liquid oxygen converters for supplying breathing oxygen to aircrew. High pressure storage bottles on aircraft suffer from both space and weight penalties which can be embarrassing to modern aircraft design. In addition, because of their high working pressures, the bottles must be protected from shattering should they become damaged by enemy action. The low pressure converter as shown diagrammatically in Fig. 5 avoids this difficulty as well as giving savings in both weight and space.

It consists of an inner sphere suspended inside an outer sphere with a vacuum between the two shells. Liquid oxygen inside the inner sphere is allowed to vaporise by means of local heat supplied to the vaporising coil. The method of operation can be followed by reference to the circuit diagram. Essentially the operation is similar to a stand tank with the addition that a control mechanism regulates inside the converter usually between 70-100 psi.

Liquid is fed into the converter via the self-sealing coupling (7) and gases created by cooling down vented through the vent and build-up valve (8). Once full the liquid is prevented from flowing out of the inner container by the self-sealing coupling (7) and the liquid check valve (2). When the gas pressure in the converter falls below its design setting the pressure closing valve opens allowing the gas pressure above and below the liquid to

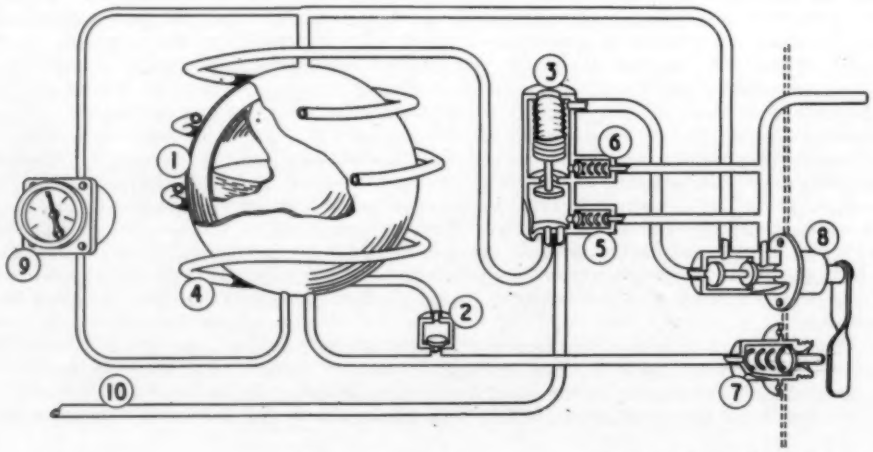


Fig. 5. Circuit diagram for liquid oxygen converter. This type of converter has many advantages over the high-pressure type.

equalise. The head of liquid above the check valve (2) opens this valve and allows some liquid to trickle through into the evaporating coil (4). Here the liquid is evaporated by atmospheric heat and the gaseous oxygen passes through the circuit and eventually back to the gas space in the top of the converter thus raising its pressure. When the working pressure is reached the bellows in the pressure closing valve contract and automatically shut, thus preventing any further oxygen passing into the gas space of the converter. Any further liquid evaporating in the coil shuts the liquid check valve (2) by building up pressure between it and the pressure closing valve (3). This prevents any further outflow of liquid oxygen into the evaporating coil (4).

A demand for gaseous oxygen via supply line (10) results in a reduction of pressure in the evaporating coil (4) and in particular behind the liquid check valve (2) and this valve will then open and allow further liquid to trickle out into the coil to be evaporated and meet the demand. The level of liquid oxygen can be read remotely by means of the differential pressure gauge (9) suitably calibrated. Excessive pressures in the gas and liquid phases of the converter are prevented by relief valves (5) and (6).

Purity of Liquefied Gases

Where it is necessary to store or transport liquefied gases of high purity, for example nitrogen containing a fraction of a percentage of oxygen, attention must be paid to the concentration of the less volatile gas which occurs in the liquid if evaporation occurs from the surface. Over a period of time the amount of impurity will build up in the tank as the gas given off will be richer in the more volatile component than in the liquid, and may result in contaminating the liquid especially if the tank is used for intermediate storage. The extent of change of the composition depends largely on the vapour-liquid relationships of the substances involved but also on the amount of vaporisation which occurs and the quantities of liquid filled and withdrawn from the tank.

For liquid nitrogen storage a method has been reported[5] whereby heat inleak into the tank causes evaporation of the liquid out of direct contact with the vapour as shown in Fig. 6. The vapour produced in the gas space by evaporation of the liquid, and which is richer in nitrogen than the liquid, is condensed on the outer surface of a coil by allowing an equivalent quantity of liquid to expand to atmospheric pressure through this coil. The storage pressure may be held constant by this method at the expense of the complete evaporation of liquid of composition the same as the initial contents of the tank.

The storage of liquid nitrogen at atmospheric pressure has also presented difficulties with some conventional types of insulation due to the condensation of liquid air on cold surfaces in contact with the liquid nitrogen. The heat transfer mechanism whereby heat passes into the tank is thereby amplified by high condensation coefficients which appreciably increase the evaporation losses from the tank. One method of overcoming this increased loss is to hold the liquid nitrogen at a pressure exceeding 1.7 atmospheres when its boiling temperature is higher than the dewpoint of the atmosphere. If permeable insulation is avoided, as for instance by the use of vacuum powder insulation which precludes contact between the atmosphere and the majority of the tank, then the problem of increased losses does not arise.

In the field of combustible gases the storage of liquid methane offers potentialities for combating peak load demands in the gas industry. Seasonal demands, especially where gas is employed for space heating, can cause embarrassment to the gas works and low gas pressures in the customers' supply main. A method of supplementing

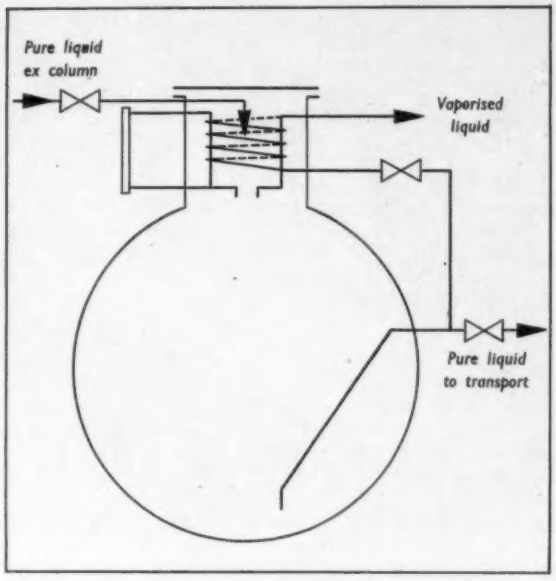


Fig. 6. Pure liquid nitrogen storage.

the coal gas with an alternative fuel gas which can be rapidly generated in a simple plant from readily stored material is an obvious solution. Such an installation for the U.K. was first suggested in 1937, in which methane could be extracted from coal gas by liquefaction and stock-piled.[6, 7] It was left to the United States, where supplies of natural gas are readily available, to erect the first installation. Following pilot plant work in 1940 three spherical containers each holding 50 million cu. ft of liquid methane (500,000 galls.) were erected at Cleveland, Ohio, in 1941. The capacity of the plant was increased in 1943 by the erection of a fourth tank of 90 million cu. ft capacity of a different type of construction, generally described as torro-segmental. The disaster which occurred in 1944 due to the failure of this latter tank and subsequent burning of the contents, which were discharged over the plant area and adjoining property at a lower elevation, must serve as an example and a reminder to those responsible for the safety angle of plant design and layout. The extensive report by the U.S. Bureau of Mines[8] of the accident could not find any definite cause of the disruption of the tank. It is felt that the use of a low carbon 3½% nickel alloy steel which did not have a very high Izod number, together with the design of the tank which permitted vibrations to be transmitted through the footings, may have caused an embrittlement fracture. Considerable inertia in the use of liquid methane has resulted from the disaster but as suggested by Haselden[9] safe storage installation with retaining walls could be designed employing metals which have proved trouble-free with other liquefied gases at even lower temperatures.

A post-war development has led to an installation in Moscow where storage of 162 million cu. ft is effected by a plurality of cylinders inside an insulated cold box. More recently a scheme is being developed in the U.S.A. to ship liquid methane from the Mississippi delta in balsa wood insulated barges in order to provide fuel for power generation and cold for refrigeration. Such a method of transportation contains the novelty that the methane evaporated during transit can be employed for propulsion of the barges. Although originally intended for Chicago the project, which is still in the experimental stage, has now altered to Cuba. The possibility of supplementing the British Gas Industry with methane from the Middle East

and Venezuela is under active consideration but the design of a suitable ocean-going tanker with a satisfactory degree of safety remains to be solved. The subject has been reviewed by Burns and Clark in a recent paper.[10]

Other combustible gases such as propane, pentane and butane are supplied in cylinders especially for domestic use, but it should be noted that the petroleum companies are now handling these liquefied gases in large bulk volumes as is illustrated by the use of sea-going vessels for liquid butane, where the gas is contained in large cylinders permanently fitted into the holds.

Liquid Helium

It is illustrative of the range of liquefied gases that can be transported that helium, a gas at the lower extreme of the temperature scale, is available on a semi-commercial scale. In the United States, where plentiful supplies of helium are available from sources other than the atmosphere, it is not unexpected that considerable attention has been paid to the design of liquefiers for this gas, and liquefiers with outputs up to 120 litres of liquid per hour have been constructed. In a paper presented at the Congress of the International Union of Physics (1955), Scott gave reference to a study of the feasibility of shipping liquid helium about the U.S.A.[11] He concluded that the ability of such a scheme to compete with high-pressure transportation of gas rested primarily upon the cost of liquefaction and that preliminary estimates indicated that a plant with a capacity of 400 litres/hour would be required to make the costs break even. A scheme is already in operation in this country based on the N.P.L. at Teddington. A Collins liquefier of rated capacity 4 litres per hour is employed and liquid helium is shipped by rail or road in 15 litre duplex flasks such as are illustrated in Fig. 7.

Owing to the need to conserve helium, the participants in this scheme collect, where possible, the evaporated helium in plastic balloons, compress it into cylinders and return the gas to the N.P.L. for reliquefaction. The liquid helium container consists of four spheres which are extended into a long neck. Two of the spaces between the spheres are completely evacuated thus giving the normal vacuum insulation and the other interspace is filled with liquid nitrogen which is free to evaporate at atmospheric pressure. The long neck increases the heat path by conduction along the metal and the inner sphere is made of a poor conductivity metal (such as Inconel) in order to minimise also this source of heat inleak. The majority of heat inleak is therefore taken up by evaporation of liquid nitrogen, the quantity charged being almost the same as the liquid helium contents. Losses from this type of container have been reported[12] as 130 cc per day of liquid helium and 2 litres per day of liquid nitrogen. In order to keep the cooling down losses as low as possible the metal thickness of the shells have been kept as thin as possible and hence the working pressure of the container is low. Transfer of the contents is effected by a vacuum insulated transfer tube which again is very thin to avoid cooling down losses and the relative position of the container being filled is important owing to the small pressure available. It has been suggested by Scott that stronger containers be designed and the liquid helium be transported without loss by sealing the vessel. If the pressure is allowed to rise slowly to 5-10 atmospheres the helium will not necessarily be in the liquid state as the critical pressure is 2.26 atmospheres but with good liquid nitrogen protection it should be possible to keep the helium in such a condition for between 20 and 30 days.

Conclusion

The range of technology in the use of liquefied gases has increased considerably during the last decade. It has not been possible to cover as fully as the title of this paper would imply the whole field of gases which are now liquefied in commercial quantities. However, with the advances in Low Temperature Physics a wide field of application is open to chemical engineering principles and experience gained in handling liquefied gases dating from the early work of air liquefaction will prove of great assistance in the future.

A very good example of progress in the U.S.A. was given in papers presented at the 1954 Cryogenic Engineering Conference held at Boulder, Colorado.[13]

Acknowledgment is made to the Directors of the British Oxygen Company Ltd. for permission to publish this paper.

REFERENCES

1. B. Patent No. 684,230 dated 10.12.52.
2. Katan, L. L. *Vacuum*, **1**, No. 3, 191, 1951.
3. U.S. Patent No. 2,677,938 dated 11.5.54.
4. B. Patent No. 728,423 dated 20.4.55.
5. Littlewood, A. D. and Schuftan, P. M., Proc. 9th Int. Congress of Refrigeration, Sept., 1955.
6. Egerton, A. C. and Pearce, M. *J. Inst. Fuel*, **18**, 161, 1945.
7. Egerton, A. C., Hall, T. A. and Pearce, M., *Inst. of Fuel Bull.*, 193, 1946.
8. Elliot, M. A., Serbel, C. W., Brown, F. W., Arty, R. T., Berger, L. B. U.S. Bureau Mines Report Investigation 3867 (Washington 1946).
9. Heselden, G. G. and Reis, M. W., *J. Imp. Coll. Chem. Eng. Soc.*, **5**, 11, 1949.
10. Burns, J. and Clark, L. Pub. 484, Inst. Gas Engineers, 1956.
11. Scott, R. B. Paper presented at Congress of the International Union of Physics (Low Temperature Congress, Paris, Sept. 1955).
12. Wexler, A., *Rev. Sci. Inst.*, **25**, 442, 1954.
13. N.B.S. Report 3517. Proceedings of the 1954 Cryogenic Engineering Conference.

I.C.I. Participates in U.S.A. Plastics Project

I.C.I. and Hercules Powder Company of U.S.A. are to build an $11 million plant in Missouri for the manufacture of methyl methacrylate. British Treasury sanction for I.C.I. to participate in this project has been obtained. Methyl methacrylate is a chemical with many applications, although it is most commonly known today in polymeric form as polymethyl methacrylate. This is a glass-like plastic widely used in sheet form in aircraft, motor cars, and illuminated signs, and for many other purposes. (I.C.I.'s trade mark for polymethyl methacrylate sheet is, of course, "Perspex".)

The new plant, with an annual capacity of 34 million lb, will be built on a 20-acre site at Louisiana, Missouri, adjoining the Missouri Ammonia Works, owned and operated by Hercules. The new company will make and sell both monomer and polymer in various forms.

I.C.I. pioneered the process used throughout the world for the synthesis of methyl methacrylate monomer. They will bring to the new company their production, research and technical sales service experience developed over twenty years as a major manufacturer of methyl methacrylate in all its forms. Hercules, on the other hand, will bring to the new company a technical organisation experienced in U.S. production methods, and an established position in U.S. markets, plus the advantages of a site where the basic raw materials are available. Ammonia and methanol are produced at the Missouri plant, and natural gas is available in unlimited quantities from an adjacent pipeline from Texas gas fields. Hercules produces a fourth raw material, acetone, at one of its newest chemical plants in Gibbstown, New Jersey.

Methyl methacrylate is made on a large scale by only two other companies in the United States and at present its main application is as a plastic polymer. In this form, its unique combination of properties makes it particularly suitable for many and diverse large-volume uses. U.S. consumption has doubled between 1949 and 1955 and is expected to double again in the next five or six years.

The laboratory of the Ramsey Department of London's University College, where Britain's first chair of chemical engineering was founded in 1923.

THE RESPONSIBILITIES OF THE CHEMICAL ENGINEER

by J. A. ORIEL, M.C., C.B.E., M.I.Chem.E.

(*President, Institution of Chemical Engineers*)

ALTHOUGH it is three-quarters of a century since the teaching of Chemical Engineering became a part of the recognised curriculum of scientific teaching in this country, the subject did not gain much recognition here until the last two decades.

Chemical engineering developed at a great rate in the United States, both as a subject of instruction in the universities and technical colleges and as a most useful and valuable help in the rapidly growing chemical and petroleum industries. The added call in the atomic energy field has still further increased the demand for a knowledge of chemical engineering. The fact that we British were a little late entering the field need not be a permanent handicap. It is sometimes even a gain to be able to follow in the footsteps of others if advantage is taken of their experience. It does, however, throw great responsibilities upon the present generation of chemical engineers, and particularly on the younger members of the profession, to see to it that every advantage is taken of the present opportunities. As I have said elsewhere, there is nothing to be gained by comparing our position with that of the United States or Russia. The fact is that we now need chemical engineers, and we need them badly.

It is upon the manner in which the present generation develops the profession that its future will depend. The responsibility is a great one, for the subject might at this point well become one of narrow technology or an underlying basis for the development of other technologies, or indeed it might broaden out to be the finest training for life in all its spheres and could combine the scientific approach with the practical needs of the world, and not only in industry and commerce.

I do not propose to enter here into the science versus "humanities" controversy. There is no useful purpose to be gained by doing so. Of course, those who have studied the sciences are different from arts-trained people, but there is no reason why those engaged in the sciences should neglect the arts altogether. They are fortunate in that they can read and understand general literature—a benefit which is denied to their less fortunate fellow students who do not understand the language of science. This is nothing about which to boast; it is merely a fact, but the advantage is something technical men are in danger of losing if they confine the whole of their reading and living to their science or technology.

The chemical engineer occupies a unique position. His working equipment goes far beyond textbook formulæ, for he must have thorough knowledge of the basic sciences —chemistry and physics—combined with a firm grounding in mathematics. All these are part of his training and he uses them constantly and has of necessity to eschew the handbook approach. Combined, of course, with this background of scientific knowledge is his experimental approach to every new subject. This is a point to which I shall

return later. (The point I want to make is that the physical chemist and the physicist are both looking for new fields and extending the boundaries of scientific knowledge, leaving the application of these fields to the chemical engineer to develop.)

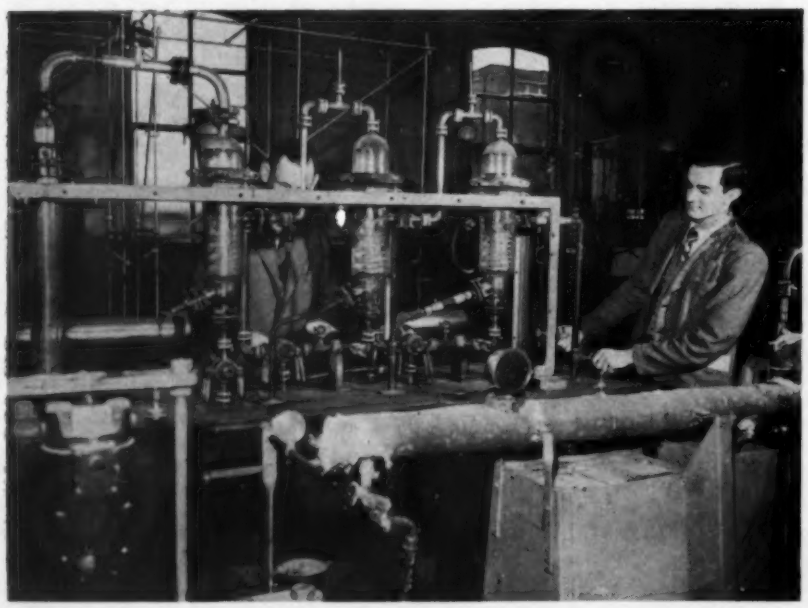
But even all this is not enough. As I shall hope to show, the chemical engineer is, more than most engineers, called upon to take part in management. It will not be enough, therefore, for him to have merely a thorough technical knowledge of his subject, but he must above all be a man with an understanding of human relations. In the process industries—the petroleum, the chemical, the atomic energy industries—the field of knowledge is developing very rapidly and I believe it was the President of du Pont's in the United States who said recently that 50% of the industrial force in the United States are working upon materials which simply did not exist 25 years ago. This is a staggering fact, and when one appreciates that the design, the development, the construction and finally the operation of the plant are almost entirely in the hands of the chemical engineer, one sees how intimate a knowledge the chemical engineer must have day by day of his operations.

This is not simply a question of designing, installing and operating equipment which, once installed, will continue to work efficiently—given intelligent maintenance—but in the process industries there is constant opportunity for experiment, in order to improve quality and increase quantity. This means that the operation of each piece of equipment is in the immediate control of a technologist concerned with the operation. For this reason, and for the reason that the process industries are of necessity very highly instrumented, the technologist is in constant day-to-day contact with the operators on the plant. This calls for men with a thorough understanding of their profession and who are also prepared to take initiative and accept responsibility.

What then is being done and what more should be done in this country to ensure that the race of chemical engineers which is growing up shall be really worthy of this country and capable of taking advantage of the opportunities before it and accepting the responsibilities required of it? The opportunities are there. The really well-educated chemical engineer is in very short supply and in very great demand, a situation which carries with it opportunities for a full and interesting life, coupled with good prospects of progress and promotion.

A great deal has been done, and a great deal more is being done. The country is now unquestionably awake to the need for technological advance. The very existence of the modern secondary school and the growing numbers of the technical schools are evidence of the Government's concern with the training of technicians. The recently published White Paper on Technical Education is equal evidence of the Ministry of Education's desire to encourage technological education in advanced technical colleges. Criticisms there may be of the Government's plans, but the fact remains that the Ministry is prepared to encourage financially the establishment of these colleges and has left it to those concerned to work out the details of the best plans they can conceive and implement. This detailed work is now in process of being carried out. There is, I think, no danger of there not being boys in sufficient numbers coming forward to enter these technical colleges. The public schools and the grammar schools are now both training far more boys in science to the advanced level than ever before, and a great many of these boys who do not, for one reason or another, wish to enter universities will unquestionably be absorbed into industries which are prepared to take part in the new sandwich-course scheme. Others will no doubt proceed direct to the technical colleges for full-time instruction lasting three years.

The universities are developing rapidly, and it can be confidently expected that the Chancellor of the Exchequer —through the University Grants Committee—will follow the lead of the Ministry of Education and grant considerable funds for the development of those universities most suited for scientific and technological development. Within recent months, Oxford has shown its interest in this subject and has been discussing the establishment of a new college in which there will be a larger proportion of science dons than there is in the older colleges. (This scheme has, however, been pared down considerably since it was first suggested.) Cambridge, too, has shown, in its latest publication on the future of the University, that it is prepared to alter its proportion of science to arts as need arises. At the same time the provincial universities are developing their technological and scientific departments as rapidly as building will allow.



The chemical engineering laboratory of West Ham College of Technology. The first "Dip. Tech." sandwich course in this subject (described in our June issue) starts there this Autumn.

(Right) The chemical engineering department of Manchester College of Technology promises to be the country's largest. It will be accommodated in a converted cotton mill in Jackson Street.

(Below) The Stephenson Building, Newcastle, houses the chemical engineering department of Durham University. The B.Sc. course started in 1955. Prof. J. M. Coulson has 20 undergraduate students, and five men engaged in research.

These last remarks cover science and technology in general, and they apply in particular to chemical engineering—which is developing more rapidly than the other technologies because of the fact that it has lagged behind during the first quarter of this century. During the past ten to fifteen years there have been established eight chairs in Chemical Engineering in British universities. Industry has played a great part in this expansion, which shows that the process industries regard this particular subject as of the first importance. The first chair to be established was the Ramsay Department at University College, London, followed by the Courtauld chair at the Imperial College of Science and Technology and Birmingham University's chair, and then by the establishment of the chair of Chemical Engineering by the Shell Company at Cambridge, whilst that company at the same time established scholarship funds at Cambridge, University College, Imperial College and London's King's College.

This then is sufficient evidence of the stirring of interest and activity in chemical engineering. But is this enough? Are we making the best use of our facilities, both in manpower and brain power, and in the equipment which we have available? Probably we are developing as fast as we possibly can as regards education up to the first degree standard, which incidentally, in the study of chemical engineering, must take at least four years. Greater use will have to be made of the technical college buildings which already exist, but of course the main limiting factor is the shortage of teaching staff. This difficulty, too, will, I think, be overcome in due course.

But whilst the great majority of those required for industry will be adequately taught up to the first-degree standard, there is still a necessity for postgraduate education in chemical engineering. Naturally a certain percentage of postgraduate students will be drawn to research, and the universities are expanding their research schools in chemical engineering to deal with this; here again industry is showing its interest by assisting in the establishment of these research schools. But there are required great numbers of men who have the ability to develop the discoveries of science into practical operation—men who are capable of keeping in touch, as it were, with the boundaries of science and at the same time of leading teams of technologists in the development of these subjects into practical operation. For these men there should be created, as I have said elsewhere, "an All Souls' of Technology." The entrants to this college should be men of outstanding ability, but not men who wish to devote all their time to research. This college should also be open to graduates and others who have already spent some time in industry. This college certainly should be residential and the bulk of the work should take the form of postgraduate *instruction*, combined with specialised lectures from experts in industry and lectures on general subjects concerned with industry. Here men will live with one another, rub shoulders with each other, exchange views and ideas and, with the impetus of general discussion during the day and the evening, will gain something in quality which is not available anywhere else. This ability to discuss one's subjects with others is of the greatest value. It may have been given to a certain Greek philosopher to develop his ideas alone in a barrel, but for us more common folk who are concerned with much greater problems we need the stimulus of discussion and of living with others in order to develop our ideas.

Here then is the opportunity for development, but I return to the point from which I started. All of this carries with it the acceptance of a heavy responsibility on those who are developing the chemical engineering in this country at the moment, whether they be teachers, managers or students, and I would like to suggest that part of their responsibility at the present time is to develop the corporate life of the Institution of Chemical Engineers. Here again, by mixing with other men of other ideas in other industries, other upbringing and training they will learn not only to appreciate other men's technical problems but also to see the broader problems which affect men's lives.

On the right the polished stainless steel nitrator, linked to the separator. In the foreground are the three washing vessels which are connected in series.

PROGRESS IN NITROGLYCERINE MANUFACTURE

The Biazzi plant at Ardeer is described in this special article, which also compares the three processes for the manufacture of nitroglycerine carried out at this centre of explosives production

by J. O. S. MacDONALD, B.Sc., A.R.I.C., A.M.I.Chem.E.

AN unusual feature of the I.C.I. Ardeer factory, where industrial explosives are manufactured, is the use simultaneously of three different processes for the production of nitroglycerine. There is the old batchwise process which has been in use since towards the end of the 19th century (some of the vessels now in use are over 60 years old), then there is the more modern and safer continuous process designed by Schmid, and finally we come to the most recent development in the field of nitroglycerine manufacture—the Biazzi process. The commercial manufacture of nitroglycerine has invariably been looked upon as one of the most dangerous operations in the explosives branch of the chemical industry. The reason for this is the extreme sensitivity of the product to detonation by friction and impact, while burning can result in an explosion.

The earliest methods of manufacture depended on the addition of glycerine to mixed sulphuric and nitric acids in jugs; the stirring was done with glass rods. Increased demand for nitroglycerine saw the replacement of these primitive devices by lead vessels fitted with cooling coils, and by the year 1870 vessels of this kind capable of producing 2000 pounds of nitroglycerine per batch were in fairly general use. An important improvement in the chemistry of the process concerned the use of anhydrous mixed acids instead of the more dilute acids formerly used. This step was successful in raising the yield of product from 85% to 95%.

Batch Process

The basic reaction involves the formation of nitroglycerine (glyceryl trinitrate) according to the following equation:

$$\begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array} + 3HNO_3 \xrightarrow{(H_2SO_4)} \begin{array}{l} CH_2ONO_2 \\ | \\ CHONO_2 \\ | \\ CH_2ONO_2 \end{array} + 3H_2O$$

The nitration is effected by the slow addition of high purity glycerine (99.9%) to mixed acid, of composition 55% sulphuric, 45% nitric. Nitration takes about 45-50 minutes to complete, and is carried out in lead nitrators large enough to accommodate a batch of 2100 pounds of product.

The heat generated by the reaction is removed by calcium chloride brine at −15°C circulating through the coil fitted inside the vessel. Air for agitation is introduced from a sparger at the bottom of the reactor. The rate of addition of glycerine to the acid is governed by the rate of removal of reaction heat consistent with a temperature of reaction in the range of 15-20°C, and the glycerine flow is regulated manually by means of a stoneware cock. Above this temperature range there is a danger of generating a violent reaction which may end in an explosion.

The entire operation of nitration is carried out in a separate building. From this stage onwards the processing equipment is duplicated, and there are provided two separators and pre-washing houses, and two washing and storage houses. This allows the operations to be carried out in physical isolation from one another. The flow from one building to the next is effected by means of open lead-lined troughs, which have a number of advantages; for example, they give a sight of the flow taking place, are less inclined to block and are easier to clean than pipes.

As can be seen from the accompanying flow sheet, nitroglycerine and spent acid are transferred to settling tanks in a separate building situated at a distance from the nitration house. The nitroglycerine (sp. gr. 1.596 at 20°C) forms the upper layer of the two phases, the spent acid (sp. gr. about 1.72 at 20°C) being the lower layer. The nitroglycerine overflows into a launder attached to one side of the rectangular lead washing tank, which is installed in the same house. The remnants of nitroglycerine are transferred to the launder manually by means of a lead ladle. After pre-washing twice with water to remove as much free waste acid as possible, the nitroglycerine is passed to the final washing stage; here it is agitated with the washing agent by means of compressed air (as also happens in the pre-washing stage). For the final washing, the washing agent is 10% sodium carbonate solution. The nitroglycerine is now transferred to a 2000 lb. capacity storage tank to be found in the same house. From there it can be discharged to a small bogy tank for transfer to the mixing plant, where it is used in making the dynamite mix.

As shown in the flow diagram (Fig. 2) the contents of the nitrator, separator and washers can be discharged to drowning tanks in an emergency; for example, when red fumes are evolved or control of temperature is lost at any of the stages of the process which are exothermic.

In the manufacture it is important that a close control is kept upon the waste acid composition for not only is there a composition having a minimum solvent effect upon nitroglycerine—a factor influencing yields—but also there is a composition range within which the nitroglycerine may be progressively destroyed. This may give rise to loss of control and to explosion.

A further factor affecting safety is the purity of the reactants. These have to comply with a stringent specification of purity, for the presence of impurities may cause

(1) firing in the nitrator
(2) slow separation of waste acid from nitroglycerine
(3) a product of less stability (which in extreme cases may lead to an accident).

The spent acid is conveyed to the denitration plant for the recovery of sulphuric and nitric acids. Before this is done it is necessary to add a small quantity of water to prevent separation of dissolved nitroglycerine in the waste acid. The nitroglycerine in the waste acid is then safely decomposed in the denitration tower.

The freezing point of ordinary nitroglycerine is about 13°C, which is too low for incorporation in dynamites to be used in most climes. For this reason it is customary to add a proportion of ethylene glycol to the glycerine to be nitrated. A proportion of ethylene dinitrate is thereby formed and this depresses the freezing point as required.

Schmid Continuous Process

At Ardeer the output of a single Schmid plant is 2500 pounds of nitroglycerine per hour. In this kind of plant glycerine/glycol and mixed acid are fed continuously to the nitration vessel. The pumping is achieved by means of compressed air at 30 psig applied to the storage tanks containing the reactants. Flow indication is by rotameter for the mixed acid and venturi meter for the glycol/glycerine. On some plants flow is controlled automatically but the general practice is to control flow by manual operation of valves in conjunction with flow meters.

The Schmid nitrator is a squat cylindrical stainless-steel vessel with an annulus bounded by tube plates. In these are expanded the tubes which provide the cooling surface. In the central channel a propeller agitator is located which rotates at about 360 rpm. The heat generated in the nitration is removed by brine at −5°C introduced into the shell of the tube nest. The reactants and products are caused to circulate upwards through the tubes. Mixed acid is fed to the base of the nitrator, and the glycerine/glycol to the top. The reaction products overflow to the main separator where a slightly acid-contaminated nitroglycerine is separated from the heavier waste acid phase.

The separator is a stainless steel vessel of square section with pyramidal ends, which is erected at the plant in an inclined position. It contains a series of longitudinally corrugated baffle plates dividing the interior into layers. Emulsion from the nitrator is fed into the entrance to this baffle system by means of a distributor. Nitroglycerine separating at any point quickly reaches the surface of a baffle plate and collects by upward displacement in the upper part of the apparatus from where it passes out through an overflow to the next stage of the process. The interface position is regulated by the waste acid discharge valve fixed at the base. As with the nitrator, the vessel is fitted with a large discharge valve so that the contents may be sent to the drowning tanks in an emergency.

From here the acid nitroglycerine is passed to a continuous washing plant. For separation on starting up a batch washing vessel is provided, because the initial nitroglycerine product may contain as much as 8% of free acid and therefore requires special treatment. After a short period of continuous nitration the product appearing in the upper part of the separator becomes suitable for the continuous washing stage. The passage of nitroglycerine to the batch washer is then stopped, and the nitroglycerine diverted to the continuous washing process whereas the waste acid is sent to the de-nitration plant.

Each washing column is about 9 feet in height and consists of a number of glass sections between which are mounted perforated 18/8 stainless steel plates, the joints being made by rubber rings. The top and bottom sections are similarly fabricated from 18/8 stainless steel; the top carries an overflow connection whereas the lower one carries connections for nitroglycerine, wash liquor and air. This last connection is arranged so that the two liquids are dispersed on entering the column (see Fig. 1).

A number of columns (sometimes three) in series are employed, each of which has its own separator. Nitroglycerine overflow from the main separator is conveyed to the base of the first column where it is intimately mixed with fresh water and discarded washed liquor from the second column separator. Dispersion of the nitroglycerine is accomplished by ejectors which use compressed air as their source of power. Nitroglycerine issuing from the first column separator now flows to the base of the second

column, where it is mixed with the discarded liquor from the third column. Here again compressed air is used as the means of dispersing the nitroglycerine. The aqueous effluent from the first column is transferred to a denitration stage. The nitroglycerine from the second column separator is now passed to the base of the final column, having been dispersed by air as with the other columns but in 12% sodium carbonate solution. The nitroglycerine emulsion discharged from this column is then transferred to a final separator in the nitroglycerine storage house. The temperature of the washing process is about 20°C.

It will be noted that although the columns operate with co-current flow for the two phases fed to them the flow of sodium carbonate solution and nitroglycerine to the washing plant as a whole are in opposite directions. This gives economic use of the washing agent. The temperature reached in the operation of the washers is about 20°C. A feature of the Schmid process is that all the reactants —mixed acid, glycerine, water, and sodium carbonate solution—are fed to the plant under low air pressure (30 psig) taken from the same reservoir, so that any inadvertent variation in air pressure affects the flow of reactants in the same way.

This process has pronounced advantages over the batch-wise process in that the amount of sensitive nitroglycerine present in the nitration, separating and washing stages is very much reduced. However, objections can be levelled at the process because sensitive un-emulsified nitroglycerine must still be present in the upper part of the main separator as well as in the separator following the first washing column.

One great virtue of the more recently designed Biazzi plant is the significant reduction it achieves in the quantities of sensitive nitroglycerine present in these stages of the Schmid process.

This process, since it employs mechanical agitation, avoids the disadvantages associated with air agitation which one encounters at batch plants. Thus where mechanical agitation is employed the following advantages are obtained:

(1) Nitric acid is not carried away from the mixed acid.
(2) Water is not added to the mixed acid.
(3) The vortex provided by agitation draws the glycerine under the acid and thereby reduces the hazard of firing.
(4) Fog is minimised and brown nitrogen dioxide fumes are more readily detected.

The first of these advantages might be expected to lead to higher yield, but actually the yields obtained by this continuous process are not higher than by the batch process. This is because the nitroglycerine formed in the nitrator is always in contact with an acid of composition detrimental to the stability of nitroglycerine, which condition occurs only at the end of a batch nitration.

A number of safety devices are incorporated in this plant. Automatic controls are connected to both nitrator and separator which ensure that in the event of an undue temperature rise in either vessel, the contents of both vessels are dropped into a drowning tank containing 4000 gallons of water. This mechanism is actuated by means of contact thermometers which act on electro-magnets through intermediate relays. Simultaneously with the drowning of the charge, additional water is turned on to the drowning tank and air agitation of this tank is started. Drowning by hand can also be effected from various points in the plant. In the event of a power failure, glycerine and mixed acid flows are automatically cut off, leaving the plant in a position for a normal close-down.

Table 1. Comparison of different processes.

Nitroglycerine present at various stages of nitroglycerine manufacture: output of plants. 2500 *lb.*

Process	Nitrator	Separation & Washing	Total sensitive nitroglycerine present (excluding storage)
Batch	2100 lb.	4200 lb.	6300 lb.
Schmid continuous*	210 lb.	1000 lb.	1000 lb.
Biazzi continuous*	170 lb.	1180 lb.	125 lb.

*Klassen and Humphrys, *Chem. Engng. Progr.*, 1953, **49**, 643.

The Biazzi Process

In the general layout and construction of a Biazzi plant a number of steps have been taken to eliminate the possibility of the retention of even the minutest pockets of nitroglycerine. All the vessels, which are fabricated from 18/8 stainless steel, are highly polished internally to prevent adherence of nitroglycerine (as occurs on rough surfaces) and they are provided at their lowest points with drainage connections for discharging of any accumulation of product. The coils in the nitration vessel are also highly polished. The nitrator and the washing vessel agitators have their blades mounted on plates which are dished slightly and perforated to avoid trapping of nitroglycerine. Baffles also are avoided in the construction of the nitrator

Table 2. Comparison of Biazzi Process with alternative processes for nitroglycerine manufacture.

Process	Safety	Yield	Raw Materials	Utilities	Labour	Space
SCHMID	(1) Greater, due to less sensitive nitroglycerine present. (2) Less likelihood of freezing nitroglycerine at nitrator due to higher coolant temperature.	No significant difference	Sodium carbonate consumption greater	(1) Water less. (2) Power for refrigeration less. (3) Power for compressed air less.	No difference	Less
BATCH	Much greater due to (1) and (2) above, but in greater degree. (3) Mechanical agitation and avoidance of air agitation.	No significant difference	Sodium carbonate consumption greater	(1) Water less. (2) Power for refrigeration about 30% less. (3) Power for compressed air less.	Halved	Much less

and separator. Connections between vessels are direct without intervening valves, and they are given sufficient fall to prevent internal pocketing of nitroglycerine. Connecting pipework also carries in each case a glass section for inspection of flow. Fluon sleeves are used for making the joint from glass to metal pipe. The mechanical design has therefore produced a plant in which the retention of even a droplet of nitroglycerine upon its working surfaces is a virtual impossibility. This attention to minute detail, which is characteristic of the design of the plant, has been an important factor in achieving the high degree of safety typical of such plants.

Nitration

The main essentials of the process are outlined in the flow-diagram (Fig. 3) glycerine, ethylene glycol and mixed acid are stored externally in separate tanks, the acid tank being constructed of 18/8 stainless steel. The mixed acid is transferred to the reactor by means of a centrifugal pump, passes through a strainer and is delivered at a controlled rate of flow by means of a rotameter, controller and valve. The glycol/glycerine pass through a strainer and are delivered to the nitrator at the correct rate by means of an adjustable stroke piston metering pump. In the case of a mixed acid, in order to test the accuracy of flow a metering vessel is provided in a by-pass line. The flow through the flow meter may be diverted into this vessel and the time taken to deliver a certain quantity noted. This is checked with the flow meter reading. The diverted quantity of mixed acid may then be returned to storage. A similar measure is adopted for checking the glycerine/glycol flow; before a nitration is commenced, the delivery from the metering pump is checked by observing the time to deliver a certain volume. For this operation the glycerine/glycol flow is diverted from the nitrator to a suitable container whose contents, after the check, are returned to storage.

The nitrator is an unlagged and unbaffled stainless steel vessel. It is approximately 2¼ feet diameter and 3 feet in height. Agitation is by means of a shrouded turbine with backward curved blades (of approximately 8 in. diameter) rotating at 750 rpm. The agitator drive is by vee belt, power being supplied by a motor mounted in a room separated from the nitration plant by a wall. The part of the drive situated in the nitration plant is totally enclosed. An interesting feature of the drive is the provision of a flywheel on the motor shaft. This gives a steady acceleration on starting up and allows agitation to continue for a short while after switching off the motor's power supply. The vessel bottom is dished and flanged and incorporates a quick opening flush seating valve which can be operated either manually or pneumatically by means of a lever and toggle joint mechanism. The valve is placed considerably off the axis of rotation of the agitator. To help maintenance and inspection of the agitator and coils, the vessel is supported in such a manner that it can be lowered readily once the cover bolts have been removed. The reactants, mixed acid and glycerine/glycol, are fed separately into the vessel, the acid by a single pipe and the glycerine/glycol by means of a nozzle which divides the mixture into a number of streams before it comes into contact with the acid. The glycol/glycerine feed pipe is movable and may be lifted clear of the vessel, when it is desired to stop the flow of these materials to the vessel. The feed arrangements are such that fresh acid and material to be nitrated on entering the vessel are immediately pulled beneath the surface and are carried down the central space formed by the coils. Heat of reaction is removed by sodium nitrate brine which is circulated through a system of five concentric helical coils. The outside diameter of the tube employed for these coils is $\frac{9}{16}$ in. for the three outer coils and $\frac{1}{4}$ in. od. for the two inner coils. The total surface provided by this coil system is about 125 square feet.

The Separator

The emulsion overflowing from the nitrator passes to the main separator. The separator is a shallow stainless steel vessel with conical top and base. It has a maximum diameter of about 5½ feet and a height of 3½ feet. Unlike the Schmid separator, it is devoid of internal baffling. Of importance is the tangential inlet which causes a slow rotation to be imparted to the intermediate emulsion layer, thereby improving the emulsion breaking process and avoiding local overheating and dead spots. The separated nitroglycerine overflows into the sight-glass section fitted to the top of the separator and is conveyed through a short section of wide bore piping including a glass section, to the washing vessels. As with the nitration vessel, an emergency drowning system is provided in the form of quick operating dumping valves which may be either manually or pneumatically operated. The spent acid flows from the base of the separator to a variable level overflow by means of which the position of the nitroglycerine spent acid interface may be controlled. Adjustment of the overflow may be effected either manually or automatically according to the position of the interface. The principal advantage of the Biazzi separator is the small quantity of separated nitroglycerine (about 110 lb.) present at any time of normal operation. This has to be compared with the 2000 lb. or more with the batch process and about 1000 lb. in the Schmid separator. The nitroglycerine from the separator contains about 5% nitric acid and 0.3% of sulphuric acid, which must be removed in order to obtain a stable product. For this reason it is necessary to wash this impure nitroglycerine continuously with 12% sodium carbonate solution in a battery of three vessels.

Washing Vessels

In this process the flows of nitroglycerine and carbonate solution are co-current, although it is possible to arrange counter-current flow if this is required. The first vessel is provided with a jacket through which water is circulated for removal of heat of neutralisation. The temperature in this vessel is not allowed to exceed 32°C. In construction the vessels are again of stainless steel, 19 in. diameter and 33 in. in height but unlike the nitrator and separator are baffled. Agitation is also similar to that of the nitrator, the shaft speed being 750 rpm, the drives totally enclosed with remote installation of the motors. These vessels are provided with dumping valves (in the same manner as the separator and nitrator) for discharging contents to drowning tanks in the event of danger. The first vessel is provided also with a fume outlet. Sodium carbonate solution is fed by gravity from a steam-heated storage tank to the washing vessel; control at present is obtained by means of a rotameter and valve. Quick-opening Fluon lids are provided for these vessels.

Spent Acid Storage

When the plant has to be shut down it is necessary to remove all the nitroglycerine from the nitrator separator system. This is done by introducing spent acid from an over-head storage tank into the bottom of the nitrator until all its nitroglycerine has been displaced to the separator. The overflow on the separator is adjusted in such a manner as to cause all the nitroglycerine content of the separator to be discharged to the first washing vessel. While this is being done agitation is maintained in the washing vessels.

As soon as the nitroglycerine from the nitrator separator system has been transferred to the first washer the agitator of this vessel is stopped and the contents transferred to the next washer through connections at the bases of each vessel.

The suction set up by the agitator in any one washing vessel is sufficient to draw in the contents of the preceding vessel once the agitator of the latter has been stopped. The contents of the various vessels can thus be transferred finally to storage.

Automatic Control and Safety Devices

The Biazzi plant incorporates a number of control arrangements whose main purpose is the maintenance of safe working conditions. The various devices aim to minimise the effects of errors in operation, to indicate to the operator when the process is not working properly, and to set in motion mechanisms for restoring the proper working conditions when human intervention is unable to do this.

Before a nitration can start, the following safety precautions have to be observed:

(1) The safety system as a whole must be energised.
(2) The agitator of the nitrator must be rotating at its normal rpm.
(3) The mixed acid head tank must be full.
(4) The rate of acid feed to nitrator must be correct.
(5) The pressure and flow of brine to the nitrator cooling system must be adequate.
(6) The temperature of nitrator contents is normal.
(7) The air supply for pneumatically operated devices is in order.

Nitration cannot take place unless all these conditions are satisfied, otherwise, it is impossible to lower the glycerine feed pipe to the nitrator. If conditions likely to be dangerous arise during operation then this feed pipe will be raised from its position automatically and the mixed acid pump will stop feeding the head tank. This action will take place when any of the following conditions occur:

(1) There is an interruption of electrical supply to the security circuit.
(2) The speed of rotation of agitators in nitrator or first washer falls by more than 30%.
(3) The acid flow is below the speed limit.
(4) The temperature of nitrator or separator reaches the first safety limit.
(5) Brine or air pressure drops.
(6) Nitrator or separator contents are drowned.

A number of visual and audible alarms are provided to denote various deviations from the desired conditions. Thus certain irregularities in operation will cause a red light to blink, a bell to ring and a message indicating the trouble to appear upon an illuminated panel. Other undesirable conditions may be indicated by a red light; this applies when:

(1) the temperature in the nitrator is either too low or too high;
(2) the temperature in the separator is too high;
(3) the rpm of nitrator or first washer is below normal;
(4) the flows of soda solution, brine or mixed acid decrease;
(5) air pressure or actuating controls falls.

In addition, a hooter sounds if the mixed acid flow falls below the safety limit. The nitrator and separator have a second safety limit which if exceeded leads to the automatic discharge to drowning tanks of their contents as well as those of the washers. A separate tank is provided for drowning the washer contents. The drowning process itself is also carried out automatically, so that immediately any material is discharged for drowning a system of water jets is put into action. When the tank is full the water supply is automatically stopped and compressed air admitted to keep the contents agitated.

The system as described does not as yet include automatic control over the waste acid—nitroglycerine emulsion interface at the separator. The problem here is to find the most satisfactory method of interface detection. Whichever method is used, it can be possible to employ it in conjunction with a suitable controller and actuating device for altering the height of the waste acid overflow according to the position of the interface. At the same time, it is possible to televise a view of the interface to a distant point; here the overflow position can be regulated by manual adjustment of the compressed air supply to the overflow actuating device.

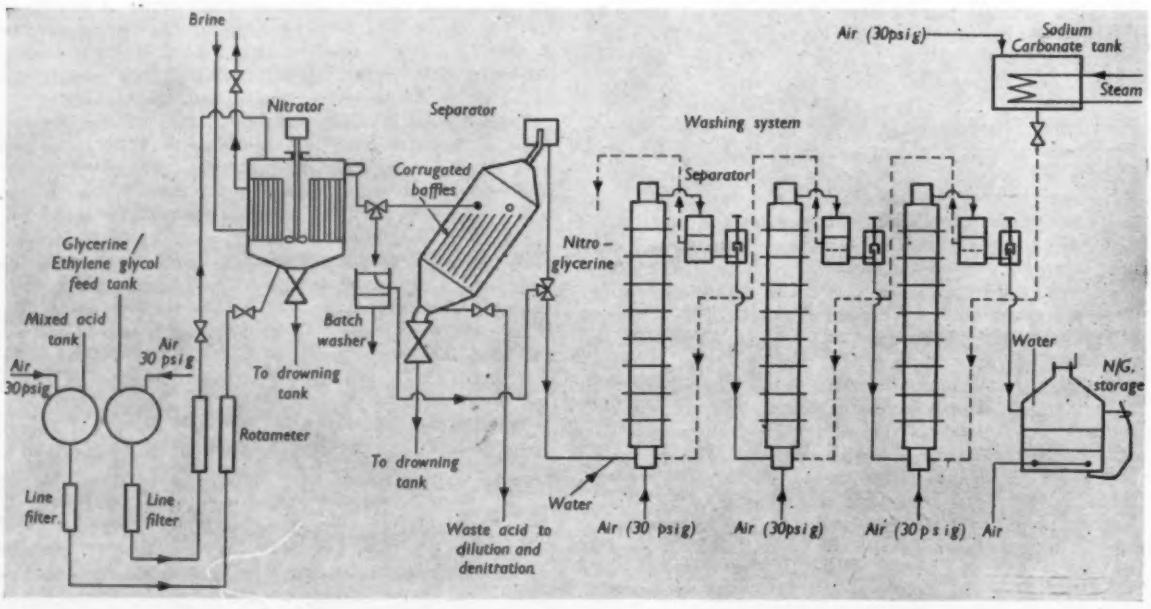


Fig. 1. Flow diagram of typical Schmid continuous nitroglycerine plant with countercurrent washing of nitroglycerine.

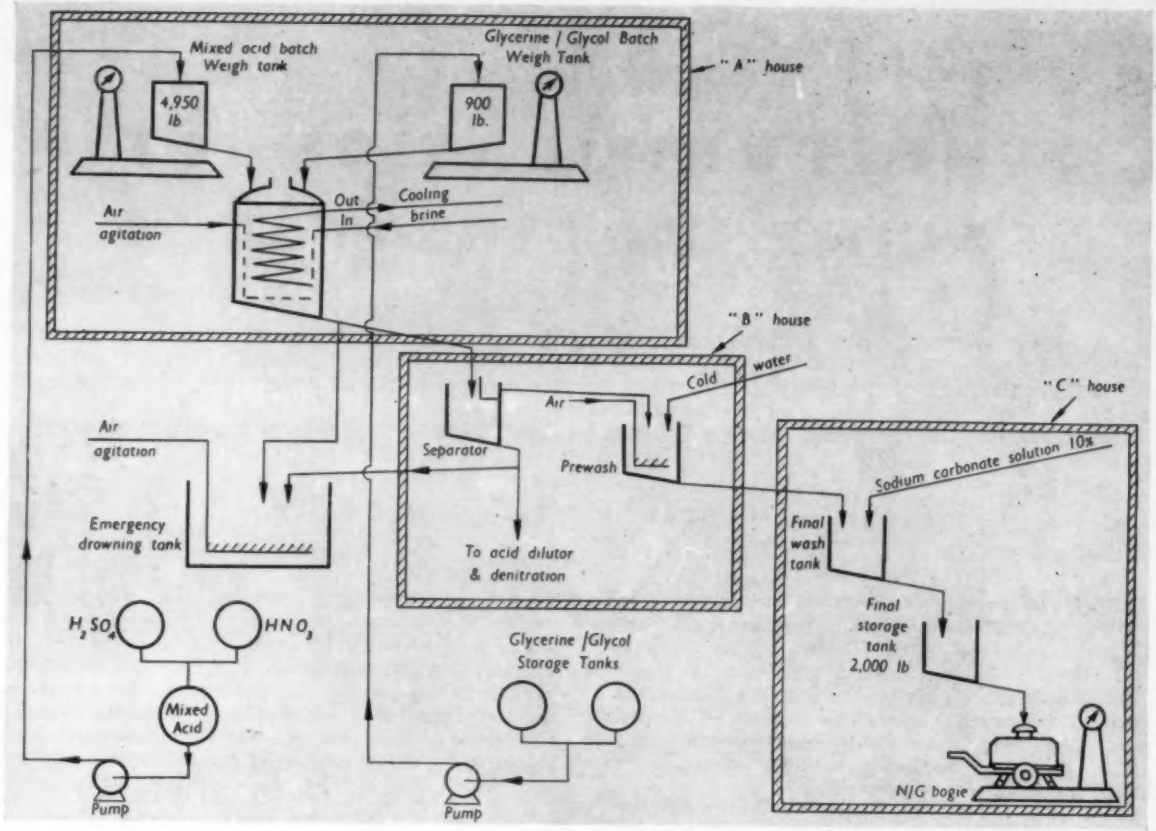


Fig. 2. Flowsheet for nitroglycerine manufacture employing batch process. Vessels are fabricated in lead.

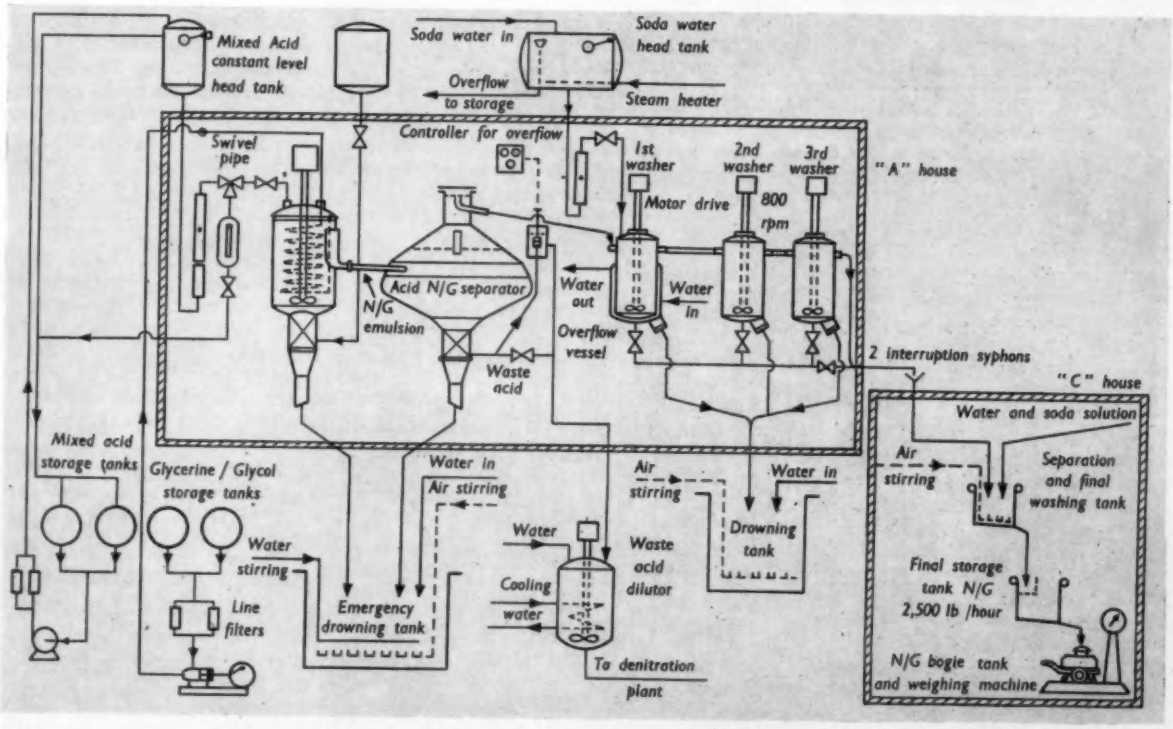


Fig. 3. Flowsheet for nitroglycerine manufacture employing the Biazzi continuous process.

THE PURIFICATION OF SALINE WATERS—Part 2

A major factor limiting industrial and agricultural development in many countries is the shortage of fresh water. Various de-salting techniques including ion exchange, electrodialysis, osmosis and solvent extraction are discussed and evaluated

by J. LEICESTER, M.I.Chem.E., A.I.Mar.E.*

IN all distillation processes for the purification of saline waters, the fundamental unit operation is the removal of water from the raw feed by the application of heat, leaving behind the concentrated brine solution. The costs of this process are therefore more or less independent of the salt concentration in the raw feed water; therein lies one of the main reasons why vapour re-compression or multi-effect flash distillation becomes competitive with other processes for the purification of sea water or high-saline brackish waters containing over, say, 5000 ppm Cl.

In the case of ion exchange, the salt is removed from the water by adsorption on the ion exchange resins, and these are capable of regeneration on a cyclic basis by the use of acid and alkaline regenerant solutions. The technique of electrodialysis using semi-permeable ion exchange membranes transfers the negative and positive charged ions through the appropriate cationic and anionic semi-permeable membranes, the electromotive force being provided by the electrical current applied across the cell assembly. Both these processes have operating and investment costs that are directly related to the salt content of the water, and to a much smaller extent the designed throughput of the equipment. Hence, they are particularly attractive for the purification of brackish waters with low salt content, and not for the more concentrated saline waters.

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Ion Exchange

The principles of this method are so well known that it is unnecessary here to discuss the technical details involved. It is sufficient merely to outline the general sphere of usefulness of this method and the operating costs entailed. The de-salting of sea water containing some

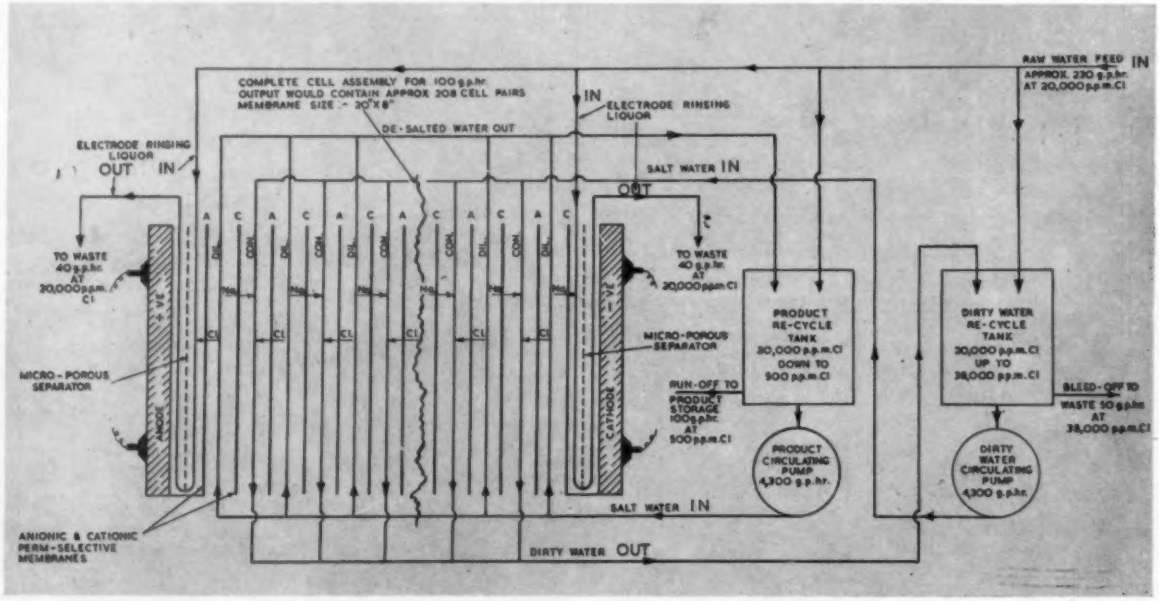

COMPLETE CELL ASSEMBLY FOR 100 g.p.hr. OUTPUT WOULD CONTAIN APPROX 208 CELL PAIRS MEMBRANE SIZE :- 20"X8"
DE-SALTED WATER OUT
ELECTRODE RINSING LIQUOR OUT IN
IN
ELECTRODE RINSING LIQUOR
SALT WATER IN
OUT
RAW WATER FEED IN
APPROX. 230 g.p.hr. AT 20,000 p.p.m.Cl
TO WASTE 40 g.p.hr. AT 20,000 p.p.m. Cl
TO WASTE 40 g.p.hr. AT 20,000 p.p.m.Cl
MICRO-POROUS SEPARATOR
PRODUCT RE-CYCLE TANK 20,000 p.p.m.Cl DOWN TO 500 p.p.m.Cl
DIRTY WATER RE-CYCLE TANK 20,000 p.p.m.Cl UP TO 38,000 p.p.m.Cl
MICRO-POROUS SEPARATOR
RUN-OFF TO PRODUCT STORAGE 100 g.p.hr. AT 500 p.p.m.Cl
BLEED-OFF TO WASTE 50 g.p.hr. AT 38,000 p.p.m.Cl
PRODUCT CIRCULATING PUMP 4,300 g.p.hr.
DIRTY WATER CIRCULATING PUMP 4,300 g.p.hr.
ANODE
CATHODE
SALT WATER IN
ANIONIC & CATIONIC PERM-SELECTIVE MEMBRANES
DIRTY WATER OUT

Fig. 7. Flow diagram of a typical electrodialysis unit: parallel flow, batch process.

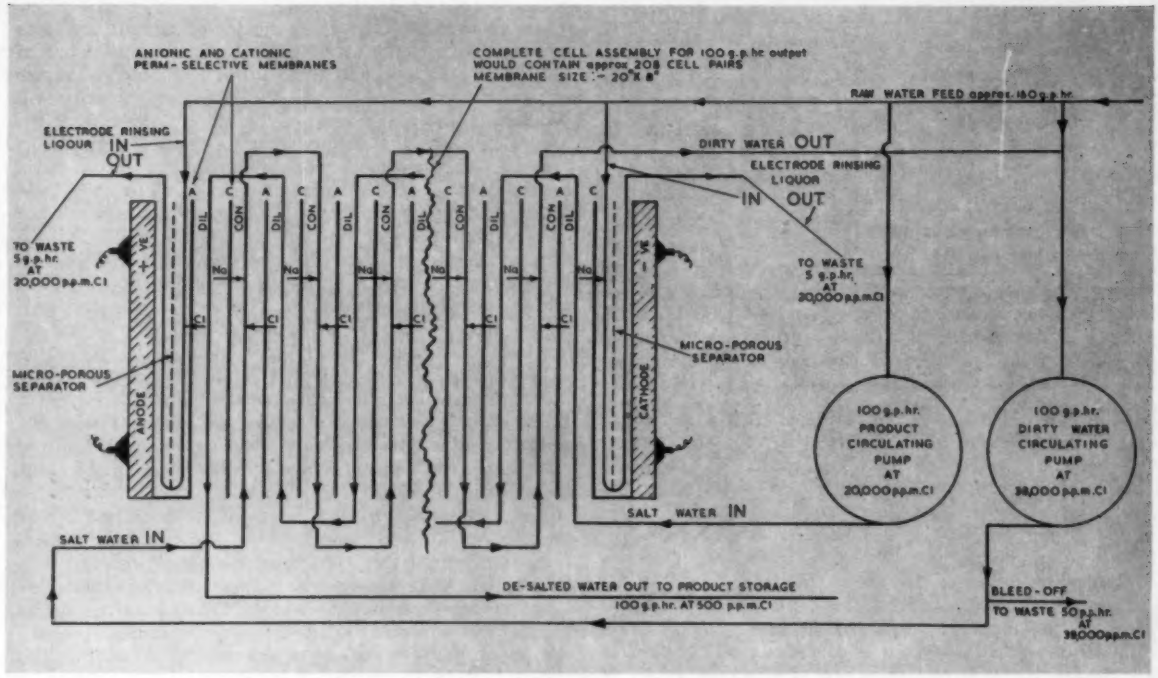

ANIONIC AND CATIONIC PERM-SELECTIVE MEMBRANES
COMPLETE CELL ASSEMBLY FOR 100 g.p.hr. output WOULD CONTAIN approx. 208 CELL PAIRS MEMBRANE SIZE :- 20" X 8"
RAW WATER FEED approx. 150 g.p.hr.
ELECTRODE RINSING LIQUOR IN OUT
DIRTY WATER OUT
ELECTRODE RINSING LIQUOR IN OUT
TO WASTE 5 g.p.hr. AT 20,000 p.p.m.Cl
TO WASTE 5 g.p.hr. AT 20,000 p.p.m.Cl
MICRO-POROUS SEPARATOR
MICRO-POROUS SEPARATOR
ANODE
CATHODE
100 g.p.hr. PRODUCT CIRCULATING PUMP AT 20,000 p.p.m.Cl
100 g.p.hr. DIRTY WATER CIRCULATING PUMP AT 38,000 p.p.m.Cl
SALT WATER IN
SALT WATER IN
DE-SALTED WATER OUT TO PRODUCT STORAGE 100 g.p.hr. AT 500 p.p.m.Cl
BLEED-OFF TO WASTE 50 g.p.hr. AT 38,000 p.p.m.Cl

Fig. 8. Diagram of typical electrodialysis unit: series flow, single pass.

20,000 ppm of dissolved solids can be achieved, but only at the expense of large quantities of sodium hydroxide and sulphuric acid for regeneration of the ion exchange resin. Since the quantity of chemicals required for regeneration are roughly proportional to the amount of salt removed, the process becomes too costly to be of interest for large scale water de-salting. It is a process essentially attractive for de-salting water containing a few hundred ppm of salt, and for salt concentrations of 1000 ppm Cl and over it becomes entirely uneconomic. Suggestions have been made, and experiments carried out, on alternative methods of regenerating the ion exchange resins. One possibility would be the use of ammonium carbonate solution, followed by heating and stripping the effluent to obtain ammonia and carbon dioxide, which could then be recombined to produce fresh supplies of regenerant. The operating cycle would be to pass the salt solution through the column, when the effluent containing ammonium carbonate could be heated and made to yield ammonia, carbon dioxide and the purified water. Such a process would involve the use of heat energy in place of an expendable regenerant chemical. However, even under the most favourable conditions, it is not considered that this modified ion exchange process could compete at a salt level much above 2000 ppm Cl and the probable cost of the purified water (according to the source of heat available) would not be likely to be less than 15 shillings per 1000 gallons.

Electrodialysis

This process offers one of the most attractive and promising techniques for the de-salting of brackish waters in the range up to 5000 to 8000 ppm Cl content.

From the latest cost data available to the author, it would appear that this process does not offer as great a cost reduction as was at first thought to be the case. Many data quoted during the past year have given a very low cost per 1000 gallons of water de-salted. These figures, however, must assume a very much higher membrane efficiency than is at present available and only a proportion of the total plant and operating cost of installed equipment. It is considered that the costs quoted in the present article represent a much truer assessment of the possibilities of electrodialysis. Certainly, membranes with greatly improved electrical properties will be developed but even assuming the corresponding reduction in electrical power consumption and effective membrane area, costs for these membranes will be a major item in the plant investment charge.

The principle of membrane demineralisation has been known for many years,[15] but practical use of the method has awaited the development of suitable perm-selective membranes and materials of construction for the cell assembly.[2,3,5,7] Briefly, the process uses the property of certain plastic membranes, in which have been compounded anionic and cationic ion exchange resins which will pass selectively the appropriate cations and anions present in the water. Electrodes are placed at either end of a stack of these membranes, and on passing an electric current the various anions and cations in the water migrate through the appropriate anion selective or cation selective membrane. Referring to Figs. 7 and 8, a group of membranes of alternating ion selectivity (*c* and *a*) are arranged in a stack between the two electrodes. Suitable gaskets and spacers are placed between each membrane pair and liquor channels are arranged for the flow of the salty and the dirty streams of water. Rinsing water is also fed separately to the two electrode compartments; in addition, the end electrode compartments are separated from the first membrane by means of a separator made from Porvic sheeting. This latter refinement ensures that solid deposits formed in the electrode compartment cannot foul the first membrane, and also, what is more important, chlorine formed at the cathode cannot penetrate the separator, and passes away with the electrode-rinsing liquor. Similarly, at the anode, the hydrogen and caustic soda liberated are also removed with the rinsing liquor. The complete cell unit is clamped together by holding bolts or some form of strong-

For small units of up to 2500 gallons per day capacity:	Present Costs	Future Costs
	shillings per 1000 gallons	
3,000 ppm down to 500 ppm	34.7	30.6
5,000 " " " 500 "	39.0	33.1
10,000 " " " 500 "	49.6	39.6
15,000 " " " 500 "	60.2	46.0
20,000 " " " 500 "	70.5	52.6
For larger multiple units up to 250,000 gallons per day:		
3,000 ppm down to 500 ppm	12.2	8.2
5,000 " " " 500 "	16.2	10.1
10,000 " " " 500 "	24.4	15.2
15,000 " " " 500 "	34.3	20.5
20,000 " " " 500 "	44.1	25.6

back device which makes the complete pack a watertight unit. On the passage of an electrical current, the product cells become purified and the concentration of salt in the dirty cells rises progressively. In the case of sea water, the concentration in the dirty liquor stream may rise as high as 38,000 ppm Cl content, a small amount of the concentrated liquor being bled to waste to ensure that the concentration does not rise above this value.

Extensive development work on this technique is in progress in Holland, the U.S.A. and in Britain in an effort to make this technique one of the first methods to be used for the large-scale demineralisation of brackish waters in the arid regions of the world. The work in Holland[16] carried out by the Central Technical Institute of the National Council of Industrial Research in the Netherlands has already reached the stage where semi-technical work on a unit of 500 gallons per hour capacity is doing much towards hastening the day when commercial exploitation of this equipment becomes a possibility. This work in Holland has become the subject of a co-operative project under the auspices of the Organisation for European Economic Co-operation, and Britain has become an active partner in the co-operative work. Similarly, work in the United States of America sponsored by the Saline Water Conversion Programme is also being carried out by Ioinics Incorporated of Massachusetts,[17] and already they have an impressive record of full-scale electrodialysis equipment on trial throughout the U.S.A. and in other locations throughout the world. In the Union of South Africa, industry and the South African C.S.I.R. are actively pursuing their own developments of this technique, and several large-scale units are operating on brackish water from the South African gold mines. This work is playing a major part in contributing data for the full-scale operation of a plant having a capacity of approximately 20,000 gallons per day of fresh water. Work in our own country is being carried out by the Permutit Company Limited, and William Boby & Co. who already have a number of technical-scale units on test; the former firm is also carrying out considerable development work on new types of semi-permeable membranes and on improved designs of electrodialysis equipment.

With all this effort, what are the present and future prospects of this method of water de-salination? Cost estimates produced by a recent O.E.E.C. Working Party and various operating costs quoted from plant trials in the U.S.A., South Africa, the Persian Gulf area, and numerous calculated costs based upon pilot plant experiments all agree reasonably well and indicate total operating costs shown in the accompanying table.

It will be readily appreciated that in addition to the separation of the salt from the solute, energy must be supplied to overcome the electrical resistance of membranes and liquor, to pump the water through the cell, to make up current leakages in the liquor circuits and also non-selectivity of the membranes. Resistance losses are of the typical I^2R type and these losses will decrease as the square of the current, whilst the de-salting capacity will decrease as the first power of the current. To reduce the resistance losses, low throughputs are required, but unfortunately for the design of equipment, this factor is in opposition to capital investment charges, as to keep these costs down high throughputs per unit are desirable. Power consumption for salt removal is directly related to the weight of salt removed, and consequently this process becomes more attractive for the de-salting of the lower saline content brackish waters. The other major cost item in the process is likely to be the cost of semi-permeable ion exchange membranes. Present costs are in the region of 6 shillings per sq. ft, but it is anticipated that future development will considerably reduce manufacturing costs. In addition, it must be also remembered that the relatively small quantities of membrane sheeting required for trial equipment are customer-made with consequent high manufacturing costs.

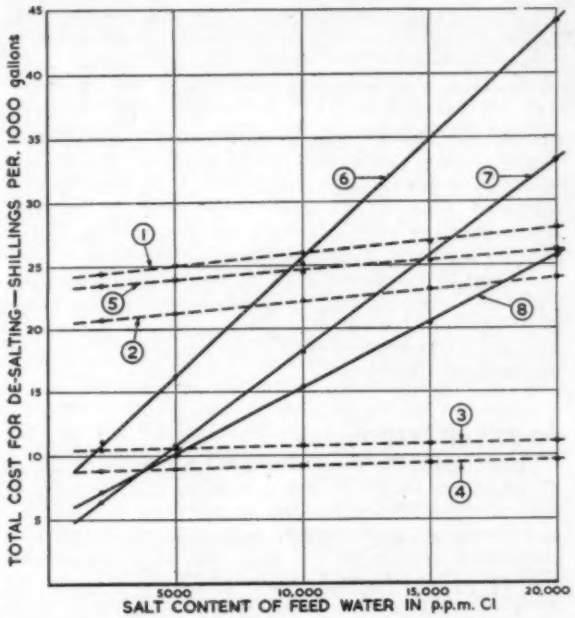
Results obtained from a series of trials carried out in the U.S.A., Holland, South Africa and the Persian Gulf area have proved the principle of the equipment, but have shown that there are several major operating difficulties. Chief among these is the tendency for scale formation on the membrane surfaces, and also in the electrode compartments. In the case of de-salting sea water or brackish waters high in magnesium salts, the alkaline condition at the anode will cause heavy deposition of magnesium hydroxide. Most attempts to date to control these deposits have relied upon the use of acid injection to control the *p*H and thus prevent deposition. Development of a method using a non-scaling electrode-rinsing liquor is however showing interesting possibilities. Solid deposits on the membrane surfaces (mainly from waters high in calcium salts) are best controlled by using a sequestering material such as sodium hexametaphosphate or sodium tripolyphosphate. These chemicals used as a threshold treatment are continuously introduced to the incoming feed water. These and several other minor operating difficulties are all under active consideration during the present series of proving trials.

Comparative Costs

Whereas the well-known technique of ion exchange has obvious advantages for de-salting waters containing up to around 1000 ppm dissolved solids, it is not an economic process for water much above this figure. Alternative techniques suggested for the regeneration of the ion exchange resin might raise the economic limit up to 2000 ppm, but above this figure the only interest can be where there is some special reason, such as ease of plant operation by unskilled labour, which could justify and uneconomic cost level for the de-salted water. Costs of ion exchange purification are not expected to drop below 15s. per 1000 gallons.

The electrodialysis process offers one of the most attractive and promising techniques for the de-salting of low saline content brackish waters in the range 700 to 5000 ppm Cl content. Considerable equipment and membrane development is in progress in many countries and already several large units have been installed and are operating under field trial conditions. There are undoubtedly difficulties ahead, mainly in connection with solid deposits forming on the membrane surfaces and also in the electrode compartments but it is considered that these will be solved in the near future. On present day performance data, it would appear that electrodialysis will only offer cheaper production of water at salt levels below and up to 2000

ppm Cl content. Above this level, some form of distillation is likely to be the cheapest method. Future development of membranes having a lower electrical resistance, lower manufactured cost and high mechanical strength is a reasonable assumption and this in turn will contribute to reduced equipment capital investment charges. Assuming membrane efficiencies can be improved by 50% and plant investment charges reduced by 50%, then the point at which electrodialysis and distillation techniques offer equal cost per 1000 gallons of de-salted water will rise to a salt level of approximately 4-5000 ppm Cl content. Unless phenomenal reductions in equipment cost can be attained, it is not considered that electrodialysis will ever be capable of competing with distillation at salt levels above 6-7000 ppm Cl content. This statement must however be qualified by the fact that for peculiar operating conditions, geographical location, etc., it may be attractive to use electrodialysis even although the cost of de-salting may be higher than by distillation. In the case of a 10,000 gph installation, costs for de-salting waters in the range 1000-5000 ppm Cl content are likely to be around 9-16 shillings per 1000 gallons, dropping to 4-8 shillings per 1000 gallons at the most optimistic future development stage. Similarly, in the range 5000 to 15,000 ppm Cl content, costs are likely to be about 16-35 shillings per 1000 gallons, dropping to a possible 8-19 shillings per 1000 gallons. For sea water (20,000 ppm Cl), present costs will be approximately 44 shillings per 1000 gallons, dropping to 23 shillings per 1000 gallons if future developments materialise. (See Fig. 9.)



1. Sextuple effect evaporation.
2. Multi-stage flash evaporation.
3. Vapour re-compression evaporation—present costs.
4. Vapor re-compression evaporation—possible future costs.
5. Solar energy evaporation.
6. Electrodialysis — present costs.
7. Electrodialysis—future costs assuming 25% improved membrane efficiency and a 50% reduction in plant cost.
8. Electrodialysis — long-term future development assuming 50% improved membrane efficiency and a 50% reduction in plant cost.

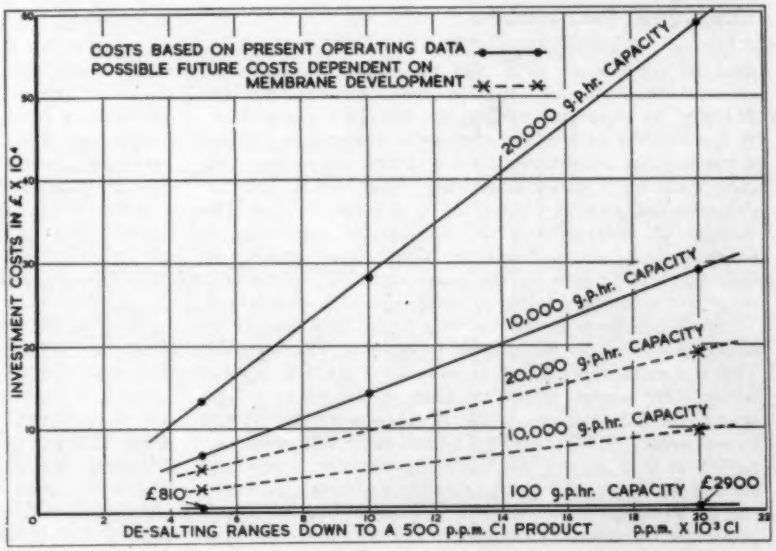
Fig. 9 (above). Comparison of de-salting costs for electrodialysis and distilation. Fixed plant capacity of 10,000 gallons per hour; product contains 500 ppm Cl.

Fig. 10. Electrodialysis costs: variations in plant investment cost with de-salting range and plant capacity.

Osmotic Techniques. De-salting of saline water by osmosis would involve the use of a membrane capable of preventing the passage of solute molecules while permitting the water to pass through. Theoretically, a suitable membrane placed between a fresh and salty stream of water should be capable of progressively de-salting the water in the cell. The movement of the water through the membrane is the reverse of the normal flow mechanism and consequently, to maintain flow in the desired direction, the salt water side must be at a higher pressure than the fresh water side. For sea water, this pressure is in the region of 350 psi to prevent normal osmotic flow. If the pressure applied is sufficient, the osmotic flow is reversed, and fresh water will be forced through the membrane into the more dilute solution. This technique is known as "reverse osmosis."[18] Laboratory studies on this method and on a technique known as the "osmionic process"[19] are being carried out in America as part of the Saline Water Conversion Programme. In this latter process, semi-permeable ion exchange membranes are used to separate the water streams, and the transfer of the appropriate anions or cations can take place through the membranes. The free energy difference between the concentrated salt and water of a lower saline concentration is the main driving force for this migration of ions.

Reverse Osmosis. Work in the University of Florida has shown that this method could be used for the purification of saline water, and that films of cellulose acetate would remove 90-95% of the salt from sea water in one pass through the test equipment. Work is at present in progress on the study of alternative films, methods of casting, testing and the determination of flow rates and durability of these films.

If this technique proves to be feasible, large-scale equipment would presumably take the form of a modified plate


COSTS BASED ON PRESENT OPERATING DATA
POSSIBLE FUTURE COSTS DEPENDENT ON MEMBRANE DEVELOPMENT
INVESTMENT COSTS IN £ X 10⁴
20,000 g.p.hr. CAPACITY
10,000 g.p.hr. CAPACITY
20,000 g.p.hr. CAPACITY
10,000 g.p.hr. CAPACITY
100 g.p.hr. CAPACITY
£810
£2900
DE-SALTING RANGES DOWN TO A 500 p.p.m. Cl PRODUCT
p.p.m. X 10³ Cl

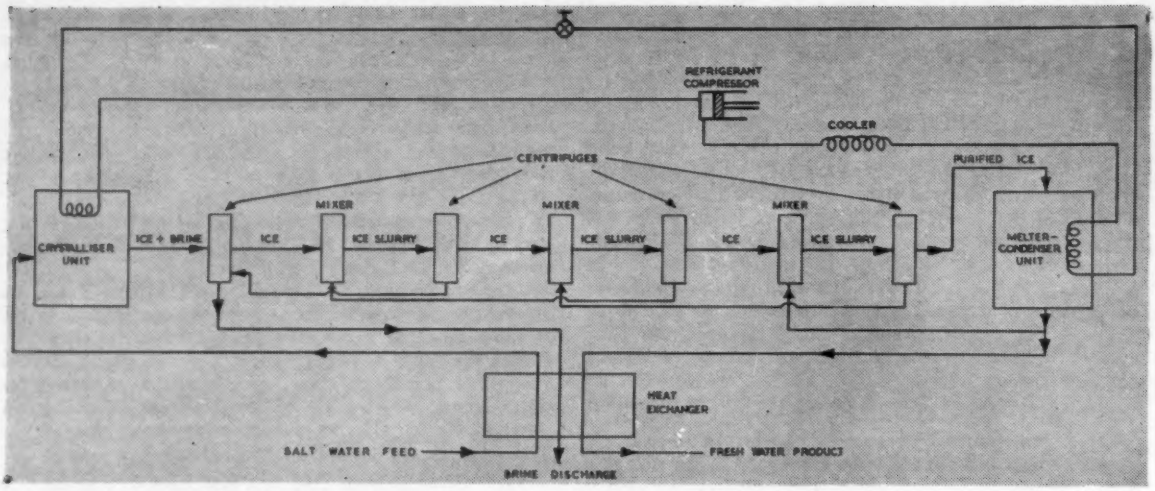


Fig. 11. *Proposed freezing system combined with countercurrent washing (after Gilliland).*

and frame or leaf-type filter press. Experiments have commenced using a small plate and frame press containing some 9½ sq. ft. of effective film area, and with water pressures in the region of 700 lb./sq. ft, yields of fresh water have been between 2 and 8 gallons per day, depending upon the concentration, pressure and temperature of the incoming water. These experiments are still only in the early development stages, and it is difficult to assess probable future trends. However, it does not appear likely at the moment that this method will provide a means of producing cheap water. Pressure requirements to force the water through the membrane are high, and even assuming a saving in pumping energy by the use of inter-stage pumps, and a recovery of pressure from the discharged brine, it would appear that the total power requirements might be as high as 30 kilowatt hours per 1000 gallons. Assuming membranes could be developed that would be durable and capable of withstanding the pressures required, rates of water production in the region of 0.5 gallons per hour per sq. ft might be achieved. A very conservative estimate would give a cost for the water produced of about 14s. per 1000 gallons.

Osmionic Techniques

Use of the concentration difference between the brine and the fresh water separated by cationic and anionic perm-selective membranes has been sugested by Dr. Murphy[19] as a possible method for de-salting saline water. In the simplest form of the equipment, two cation and two anion selective membranes form a three-compartment cell, each chamber initially containing fresh water, and the complete cell assembly immersed in a brine solution. The passage of ions through the appropriate membrane is electrostatically coupled with the simultaneous transfer of ions from the centre to the outer chamber, hence feed water in the centre chamber is progressively de-mineralised. Multiple arrangements of membrane pairs will lead to an improvement in the rapidity and degree of salt removal. This technique could be of most value to the arid regions where solar energy might be used as the primary heat source for evaporation of the raw water to maintain a steady supply of brine. Unlike typical solar stills discussed earlier in this article, the brine concentrator would not depend on a large surface area for collecting the sun's energy. Practical experiments have been carried out which prove the feasibility of the separation technique. To date, however, no pilot plant equipment has been operated which would enable a cost estimate to be produced. The method is novel and further developments should be followed with interested. There are localities where naturally occurring brines might be used to provide the concentration difference required and in this case, costs would almost entirely be related to investment costs on membranes and equipment plus relatively small power requirements for liquid pumping. In such cases, final operating costs would be very low, and might compare favourably with some of the more conventional techniques.

Freezing Techniques

Theoretically, the removal of salt from water by means of freezing is very attractive and offers the possibility of low estimates.[20, 21, 22, 23] Not only is the latent heat requirement reduced approximately sevenfold compared with evaporation techniques, but also there is a considerable amount of engineering "know-how" available in the refrigerating industry, which should be capable of being turned to good account in the present problem. One of the major difficulties, however, is that of freeing the ice crystals from occluded or adhering salt solution. Most of the development work at present in progress on these techniques is aimed at methods of separating occluded mother liquor from the salt crystals. Of the techniques already evaluated, these include gravity draining, vacuum draining, centrifuging and compression. Commercial design freezers producing a form of tube or flake ice appear to give the best results, but even these are not capable of appreciably de-salting sea water by means of a single stage of freezing. The most effective method for separating ice from the mother liquor has been found to be by compression. Pressures of 1000-2000 lb. per sq. in. will reduce the salinity of slush ice down to 500 ppm, even if the initial ice has the same salinity as sea water. High recovery values of up to 90% of the original ice fraction in the slush ice have been obtained with this technique, and work continues on this compression method of separation. Multiple-stage freezing with a conventional tube or flake ice machine has been shown to be impractical. Up to at least three stages of freezing are required to reduce the salinity from 20,000 to 500 ppm Cl, and an engineering analysis has shown that more than one stage of refrigeration would be uneconomical from an energy standpoint. There are, however, several other systems based upon the freezing cycle

which might offer an economic cost for the product, and these are described in more detail below.

Zone Freezing De-Salination

It has been mentioned above that occluded mother liquor and salt trapped in the ice crystallite makes single-stage freezing an impossibility. Multiple-stage freezing is possible, but rising costs of operation make the process uneconomic.

The technique of zone freezing is a parallel to the zone refining or purification process used in the preparation of pure metallurgical specimens. In this technique, melting of the ingot is initiated by melting a short portion at one end of a long ingot. The molten zone is caused to traverse the lenth of the ingot, melting at the front end of the zone and freezing at the rear end taking place at equal rates. Concentration of impurities takes place at the end of the ingot, due to the difference between the solubilities of a given impurity component in the liquid and solid phases of the material being purified. The possibilities of utilising this technique (that is, a frozen zone rather than a molten zone) are being investigated as a part of the U.S. Saline Water Conversion Programme.[24] Experiments to date have indicated significant variation in salt segregation by varying parameters, such as the temperature of the freezing medium, the concentration of the saline solution, the rate of travel of the frozen zone, the materials of construction of the container and agitation to maintain uniform concentration in the liquid zone. To date, experiments have shown that with temperatures in the liquid zone of around −20°C, a single pass through the equipment has resulted in a 70% separation of salt and solute. This performance would mean that only four zone passes or stages would be required to produce potable water from sea water. If the water required was only for processes other than drinking, then it might be possible to de-salt in only one pass through the equipment. This work progresses and may produce some very interesting results. It is too early yet to formulate any idea of cost estimates.

Freezing Combined With Washing

Dr. Gilliland, in a recent extensive survey[6] on fresh water for the future, has referred to freezing techniques employing multi-stage centrifuging as a possibility for the removal of occluded mother liquor. Centrifuging of the ice followed by partial melting and recentrifuging should provide a means of reducing the final salt content. He quotes the case of a series of differential stages of melting and centrifuging where the melting of 18% of the ice should be sufficient to reduce the final salinity to 1000 ppm, and by melting 25% of the ice, the salt content could be reduced to approximately 500 ppm. It is also sugested that counter current washing would be even more effective and a flow diagram is shown in Fig. 11. The possibilities of much improved heat transfer processes in the freezing cycle are quite promising, and it may be possible to replace the conventional indirect heat transfer by a system of self-evaporation under vacuum, followed by compression and condensation directly on the purified ice surfaces. Excessive vapour volumes for compression could be probably eliminated by the use of water imiscible refrigerants, such as freon, propane, butane, etc. Dr. Gilliland has forecast a probable cost estimate of 2s. 3d. to 4s. 6d. per 1000 gallons; although including total investment and operating costs, it is considered that 7s. 0d. to 11s. 0d. would be a more conservative estimate. Power required for refrigerant compression would be about 10-12 kilowatt hours per 1000 gallons.

Solvent Extraction

As part of the U.S. Saline Water Conversion Programme work has been in progress since 1953 on a method for the extraction of fresh water from sea water by the use of an organic solvent. This technique has been developed by Dr. D. W. Hood of the Texas A. and M. College.[25] The process depends upon a compound that must be a liquid, and which will absorb large quantities of water without itself suffering any chemical change and which, at the same time, must be nearly insoluble in water. The solvent compound must also be capable of giving up the fresh water when the liquid undergoes a relatively small rise in temperature. The principles of the process are shown in the flow diagram Fig. 12.

The separation of salt and water depends upon the fact that: (1) the distribution of salt between a predominantly aqueous and predominantly organic phase in heterogeneous equilibrium is high for most organic solvents, and (2) water has a differential solubility in the organic phase at different temperatures.

In practice when organic solvents, in which inorganic

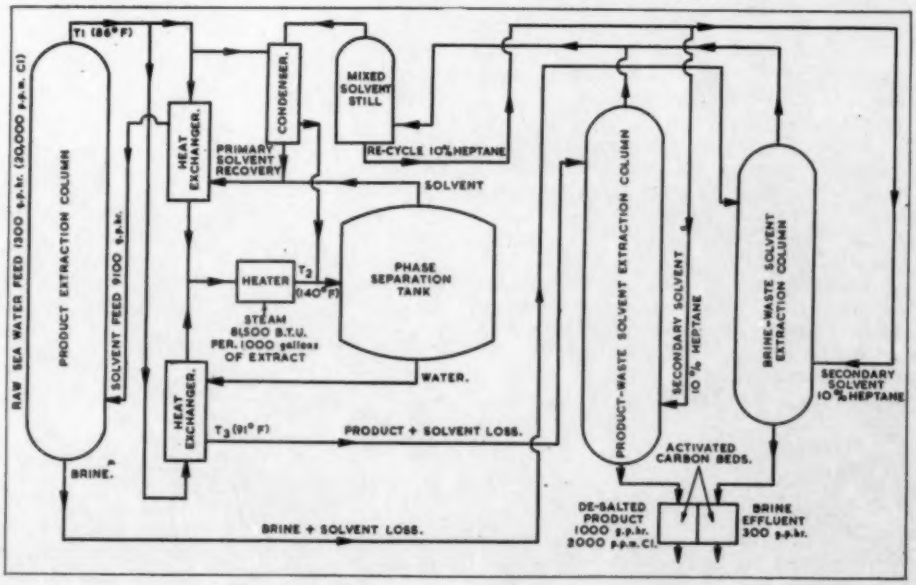


Fig. 12. Flow diagram of the solvent extraction technique for water de-salting.

salts are almost insoluble but which will dissolve large quantities of water, are mixed with the salt-bearing water, a fraction of this water will enter the organic solvent. Since the solubility of water in many organic solvents decreases rapidly with temperature in certain ranges a portion of the salt-free water may be recovered from the solvent phase merely by cooling. The solvent-saturated water phase will then be recycled with a new portion of salt-bearing water. Assuming that the solvent dissolved in the brine and the solvent dissolved in the fresh water can be removed by means of a supplementary solvent or by adsorption on activated charcoal, then the major operational cost will be energy losses through insulation, pumping and those equal to the heat of solution of the solvent/water reaction. Slight losses of solvent will also inevitably occur.

Several solvent systems have been evaluated, and both 2-ethylhexylamine and 2-ethylhexyl, 3-aminopropylether (Amine 803) have shown considerable promise. The emphasis of the present work has been directed towards methods of recovery of the small amounts of these solvents (0.2-0.4%) dissolved in the water product and in the raffinate. Experiments in a pilot plant extraction unit have shown that 2-ethylhexylamine is able to reduce the salt concentration of sea water from 3.5% to 0.36%, and if followed by a second extraction, would yield a product of 400 ppm Cl salt content. These experiments have shown that the extraction process is quite a feasible proposition. The major stumbling block seems to be the question of solvent recovery. Although losses in the product stream and raffinate are only small, the use of this technique for the large-scale de-salting of water could mean solvent losses sufficiently high to make the process completely uneconomical to operate. What are the chances of overcoming these particular solvent losses? It has already been shown that adsorption on charcoal or an ion exchange resin is not an economic possibility, at least not for the primary solvent recovery. Recent investigations have shown that the amine solvent can be reduced to less than 10% of the initial concentration by a 6-stage liquid-liquid extraction, using a 10% volume of heptane. The heptane-amine mixture is then separated by distillation, the heat of condensation of the heptane being used to supplement the heating cycle of the sea water extraction process. Removal of the final traces of solvent can then be carried out by means of activated charcoal.

Further development of this method of solvent recovery may yet bring the complete process within the cost estimates of the other more conventional methods of de-salting. Very approximate cost estimates based upon a plant capacity of 8000 gallons per hour of de-salted water show that water could be de-salted for 12-14 shillings per 1000 gallons. This assumes the use of 100,000 Btu per 1000 gallons for heating and separation of the water solvent and this figure includes 90% heat recovery by counter current heat exchange. An allowance of 100% is made for plant maintenance and overheads, a plant investment charge of £60,000 is assumed and depreciation costs taken over a 15-year period. Solvent losses are assumed to be approximately 0.01% of the re-circulation rate, and these plus the cost of solvent recovery would account for 3s. 6d. per 1000 gallons of the total production costs. Obviously the larger the size of the plant, the more economical the process. However, due to the major problem of solvent recovery, it is not thought that at the moment the process offers serious competition with distillation or electrodialysis techniques.

Conclusions

Amongst the techniques discussed in this second part of the present article, both reverse osmosis and the so-called osmionic methods of de-salination must at present be regarded as in the laboratory evaluation stage, and it is not thought that either of these methods could reach the stage of commercial exploitation within, say, the next ten years. Indeed, it may well be that with the exception of one or two specialised applications, these two methods will never provide a serious competitor for distillation, electrodialysis, freezing or solvent extraction techniques. The only cost estimate available for the method of reverse osmosis would appear to show that costs may be in the region of at least 14s. per 1000 gallons de-salted.

Purification by freezing is, I think, a definite possibility if a cycle can be worked out which, by means of repeated centrifuging and counter current washing, can successfully remove the occluded salt liquor from around the ice crystals. The relatively newer technique of zone freezing also has interesting possibilities, although it is not yet far enough advanced to be able to provide cost data or a reliable assessment of future possibilities. It would seem that some form of freezing technique will definitely enter into the field of large-scale water de-salination, and there is every possibility that costs as low as 7-11 shillings per 1000 gallons may eventually be attained.

Finally, purification by solvent extraction has been shown to be a practical possibility. The system is obviously only of interest for very large installations handling millions of gallons of water a day. Cost estimates based upon the result of laboratory trials have indicated a possible cost as low as 12-14 shillings per 1000 gallons de-salted.

It has been shown that many techniques are under investigation, some offering considerable promise of early development and application, whilst others are still very much in the experimental stage. Electrodialysis and distillation methods appear to offer the most favourable chance of early success, and there is every hope that one or other of these methods will be capable of de-salting brackish water for as low a cost as 7 shillings per 1000 gallons. Whereas the electrodialysis process will undoubtedly be the cheapest for waters up to 4000 ppm Cl, present work on heat transfer and distillation methods gives every hope that a vapour recompression type of distillation plant may prove the cheapest for waters of greater salinity. In this higher region, distillation costs will only have risen to approximately 8 shillings per 1000 gallons de-salted. It is not expected that the other methods discussed will provide any immediate solution to the problem, although their potential value may be considerable. In particular, the application of refrigeration methods may yet prove to be one of the cheapest production techniques.

The author wishes to thank the Admiralty for permission to publish this paper. The opinions expressed therein are the author's own. The first half of this article, published last month, dealt with the distillation techniques that can be used to de-salt water.

REFERENCES CONT.

[15] Single and Multi-compartment Cells for Water De-Salting: Illig. K. *Siemens Z.*, 1928, 349, Meyer, K. H. and Strauss, W., *Helv. Chim. Acta*, 1940, **23**, 795.
[16] Electrodialytic Demineralisation of Water: Sponsored Report No. 299, Central Technical Institute, T. N. O. Holland (O.E.E.C. Co-operative Project).
[17] Electrodialysis Processes: Work carried out by Ionics Incorporated, Mass., U.S.A.; Dr. W. Juda, Annual Reports 1-4 on U.S. Saline Water Conversion Programme.
[18] Reverse Osmosis: Work in progress at the University of Florida, U.S.A.; Dr. C. E. Reid (U.S. Saline Water Conversion Programme).
[19] Osmionic Process: Work in progress at the State University of New York; Dr. G. W. Murphy (U.S. Saline Water Conversion Programme).
[20] Ellis, C. B., "Fresh Water from the Oceans," Ronald Press, New York, 1954.
[21] Steinbach, A., Freezing Techniques. *Chem. Ing. Tech.*, 1951, **22**, 296.
[22] Basic Freezing Techniques: Work in progress at the Applied Science Laboratories; U.S.A., A. Rose and A. W. Hutchison (U.S. Saline Water Conversion Programme).
[23] Freezing Cycle Investigations: Work in progress at the University of Washington, U.S.A.; R. F. Moulton and H. M. Hendrikson (U.S. Saline Water Conversion Programme).
[24] Zone Freezing De-Salination: Work in progress at the Battelle Memorial Institute, U.S.A.; H. L. Goering (U.S. Saline Water Conversion Programme).
[25] Solvent Extraction Processes for De-Salination: Work in progress at the Texas Agricultural and Mechanical College, College Station, Texas, U.S.A.; D. W. Hood and K. E. Harwell (U.S. Saline Water Conversion Programme).

THE INTER-DISPERSION OF IMMISCIBLE FLUID PHASES*

by P. H. CALDERBANK, Ph.D., A.M.I.Chem.E.

The Size of Bubbles and Drops formed from Orifices

WHEN bubbles and drops are formed at infinitely slow rates from orifices, surface tension and buoyancy forces sufficiently define what is an essentially static problem. At higher rates of fluid flow, kinetic forces become over-ridingly important, and the problem infinitely more complex.

Attention is given below to the problem of estimating the bubble or drop size at the higher rates of fluid flow common in commercial operation.

In the previous section of this article, equations were developed for the bubble or drop size under the above conditions (Equations 13 and 16). These equations would be expected to apply to the bubble or drop stream under coalescing conditions when the stream has moved some distance from the orifice and the drag coefficient is predictable. However, close to the orifice, the dispersed phase is generally accelerating or decelerating and although the equations may still apply the drag coefficient is generally not predictable, since it should include the effect of varying velocity. Hughes[12] has made preliminary attempts to assess the effective drag coefficient during bubble or drop formation but more data are needed on this issue.

However, useful empirical equations for drop and bubble sizes have been reported and these equations which are discussed below will apply generally to conditions close to the orifice and to conditions distant from the orifice in the particular case of low dispersed phase hold-up (non-coalescing conditions).

Gas-bubble Sizes

For commercial gas dispersion processes, a survey shows that the range of flow rates used is between 0.1 and 0.6 cfm per orifice. Attention will therefore be directed to bubble size data obtained in this range.

Hughes[12] has shown that if the orifice is fed with gas from a small reservoir, due to resonance effects, results will depend on the particular reservoir volume used. At larger chamber volumes, the effect of the reservoir volume disappears and recent investigators have been careful to employ the latter conditions which simulate large scale equipment.

The most recent and systematic study of the size of gas bubbles formed at submerged orifices is due to Leibson *et al.*[13] Experiments were performed in which air was passed through various sizes of orifice into water and organic liquids. A careful statistical assay of bubble sizes as recorded by high speed photography was made.

Results which apply to an infinite gas reservoir volume are well correlated by the equation

$$D = 0.052\ D_o^{\frac{1}{2}}\ R_e^{\frac{1}{3}} \qquad \ldots.(25)$$

where D_o is the orifice diameter in ft.

D „ „ bubble „ „ „

$$R_e = \frac{D_o V \rho_d}{\mu_d}$$

V = linear gas flow velocity

ρ_d and μ_d = density and viscosity respectively.

This result is in satisfactory agreement with the earlier results of Davidson[14] who found:

$$D = .055\ D_o^{0.48}\ R_e^{0.32} \qquad \ldots. (26)$$

Repeated investigations (the most recent of which is due to Garber *et al*[15]) have shown that the physical properties of the field liquid play an insignificant part in determining bubbling characteristics at high flow rates. However, it must be recognised that a single equation has not yet been derived which will apply to both gas bubble sizes in a liquid field and liquid drop sizes in a gas field (atomisation). This fact suggests that one or perhaps several parameters on which bubble sizes are slightly dependent have so far not been identified.

Calderbank[16] has suggested on the basis of bubble frequency measurements that the bubble frequency for orifices and slots ranging in diameter or width from $\frac{1}{16}$ in. to $\frac{1}{4}$ in., is constant at about 17 sec.$^{-1}$. This conclusion leads to the result:

$$D = 0.48.\ F^{\frac{1}{3}} \qquad \ldots.(27)$$

where D is in ft and F, the gas flow rate in ft^3/sec. Equation 27 may be compared with equation 25 in the form:

$$D = 1.04\ D_o^{\frac{1}{2}}\ F^{\frac{1}{3}} \qquad \ldots.(28)$$

Equation 28 most clearly represents the fact that the experiments of Leibson *et al*[13] were performed with air only μ = .0435 lb./ft hr, ρ = .075 lb./ft^3. This representation is also supported by the fact that in so far as the physical properties of either gas or liquid have been varied by previous workers, little effect on the bubble size or frequency has been observed.

Table 1 compares the predictions of Equations 27 and 28.

Table 1

Orifice Diameter (in.)	Gas Flow Rate (cfm)	Bubble Diameter D— Leibson *et al*[13]	Bubble Diameter D— Calderbank[16]
$\frac{1}{16}$	.08	.0476	.053
$\frac{1}{8}$	.08	.0535	.053
$\frac{1}{4}$	.08	.060	.053
		Average ft. =0.65 in.	Average ft =0.64 in.
$\frac{1}{16}$	0.5	.0880	.0975
$\frac{1}{8}$	0.5	.0985	.0975
$\frac{1}{4}$	0.5	.111	.0975
		Average =1.19 in. ft.	Average ft =1.17 in.

*Continued from p. 209, *British Chemical Engineering*, August, 1956

It is apparent in view of the small dependence of bubble diameter on orifice size and the ultimate uncertainty in evaluating the latter for plant operating under scaling or errosive conditions, that Equation 27 is fully adequate for design purposes.

An important observation made by Leibson *et al*[13] is that, when the Reynolds number (defined in Equation 25) reaches a value of about 2000, atomisation of the gas jet with the production of many relatively small bubbles occurs. This condition is clearly associated with the onset of turbulence in the gas stream and may have important applications in gas dispersion equipment.

Thus, using a $\frac{1}{4}$ in. orifice, the bubble diameter at a gas flow rate of 0.17 cfm is about 0.9 in. At slightly higher flow rates than the above, the bubble diameter falls to less than 0.2 in.

For Reynolds numbers greater than 10,000, Leibson quotes the following equation:

$$D = 0.28.\ Re^{-0.05}\ in. \qquad \ldots.\ (29)$$

This result may perhaps be compared with that of Panasenkov[17] for the atomisation of liquids flowing turbulently in spray nozzles (Re = 1000 to 12,000).

Panasenkov gives

$$D = 6\ D_o\ Re^{-0.15} \qquad \ldots.\ (30)$$

Thus for a $\frac{1}{4}$ in. jet operating at a Reynolds number of 10,000, equation 29 predicts a bubble diameter of 0.177 in. while equation 30 predicts a drop diameter of 0.188 in. It seems possible that extended investigations of gas and liquid atomisation might lead to a common equation for both phenomena.

Liquid Drop Sizes

An excellent survey of our knowledge of the above topic has been recently made by Marshall.[18] Further discussion does not seem called for at this point except to mention the useful engineering correlation of Haworth and Treybal[19] which is not referred to in the above review.

Terminal Velocities of Bubbles and Drops

A reasonably accurate estimate of the terminal velocity of the drops or bubbles constituting the dispersed phase is of major importance in an analytical approach to the design of contacting equipment. Knowledge of the terminal velocity enables the dispersed phase hold-up to be evaluated from the relationship.

$$H = \frac{V_s}{V_t} \qquad \ldots.(31)$$

where H = fractional volumetric hold-up of dispersed phase.

V_s = superficial linear velocity of dispersed phase based on cross-sectional area of equipment perpendicular to the direction of dispersed phase flow.

V_t = terminal velocity of drops or bubbles.

From the hold-up; the interfacial contact area between phases can be derived from

$$a = \frac{6H}{D} \qquad \ldots.(32)$$

where a = interfacial area per unit volume of mixed phases.

D = bubble or drop diameter (discussed in previous section).

The bubble or drop terminal velocity is most conveniently related to its diameter by means of an experimental drag coefficient (Cd).

$$\text{Thus } Cd = \frac{4}{3}\,\frac{gD}{V_t^2} \cdot \frac{\Delta\rho}{\rho_c} \qquad \ldots.(33)$$

Free Rising Velocity of Gas Bubbles

Drag coefficients for gas bubbles rising in a variety of liquids have been reported by Garber and Peebles,[20] Garner and Hammerton[21] and Haberman and Morton.[22] The last two papers referred to are particularly concerned with the drag coefficient obtaining under commercial flow rate conditions, when bubble streams rather than single bubbles are produced. For these conditions, a constant drag coefficient of 2.6 is reported, this value being independent of the Reynolds number.

Using this value of the drag coefficient, we obtain from equation 33, assuming $\Delta\rho = \rho_c$,

$$V_t = 4.05\ \sqrt{D}\ \text{(ft/sec. units)} \qquad \ldots.(34)$$

whence from equation 28,

$$V_t = 4.13\ D_o^{\frac{1}{2}}\ F^{\frac{1}{4}}\ \text{ft/sec.} \qquad \ldots.(35)$$

and from equation 27,

$$V_t = 2.81\ F^{\frac{1}{4}}\ \text{ft/sec.} \qquad \ldots.(36)$$

For $\frac{1}{16}$ in. to $\frac{1}{4}$ in. orifices and for gas flow rates between 0.1 and 0.6 cfm (F is in cu. ft/sec.), there is an insignificant difference between the predictions of Equations 35 and 36. Thus for commercial operating conditions we may use equation 36 for simplicity without sacrifice in accuracy.

Equation 36 may be expected to apply for orifice Reynold numbers below 2000. At higher Reynolds numbers than the above, following Leibson,[13] we may conclude that the bubble diameter is fairly constant at a value of about 0.2 in. giving a rising velocity of roughly $\frac{1}{2}$ ft/sec.

Chain Bubbling

As the bubble diameter increases with gas flow rate at a greater rate than does the bubble velocity (see Equations 27 and 36), the individual bubbles in a bubble stream approach closer to each other as the gas flow rate is increased. The critical point at which the individual bubbles come into contact with each other is given by the criterion

$$nD = V_t \qquad \ldots.\ (37)$$

where n = bubble frequency.

This condition has been frequently observed in stroboscopic and photographic studies and has been called "chain bubbling". From observations of the foam density of aerated liquids Calderbank[16] concludes that chain bubbling is the normal condition obtaining on plate contactors.

In support of this observation we see that for $n = a$ constant = 17 sec.$^{-1}$ as observed by Calderbank,[16] from equations 37, 27 and 34, F_{crit} = 0.1 cfm. This shows that for $\frac{1}{16}$-$\frac{1}{4}$ in. orifices, chain bubbling takes place at all flow rates greater than 0.1 cfm per orifice. As already mentioned, this flow rate is the lower limit of the flow rates normally used in commercial practice.

Above a gas flow rate of 0.1 cfm per orifice, bubbles formed from the orifice, by pushing against the preceding bubbles may increase the velocity of rise. Alternatively, "leakage" of gas through the bubble chain may occur.

If no "leakage" occurs it may be easily shown from equations 27, 37 and 33 that above a flow rate of 0.1 cfm, the drag coefficient is given by:

$$Cd = \frac{0.308}{F^{\frac{1}{4}}} \qquad \ldots.(38)$$

where F is measured in cu. ft/sec.

Actual drag coefficients may be evaluated from foam density measurements in the following manner and com-

pared with the "no-leakage" value given by equation 16. The gas contact-time in the contactor is given by, $AS' H/F$ or S'/V_t where A is the area of cross-section of the contactor and S' the dynamic submergence of the orifices.

Thus $V_t = \left(\frac{F}{A}\right)\frac{1}{H}$ where $\left(\frac{F}{A}\right)$ is the superficial gas velocity.

Moreover, neglecting the density of the gas compared with that of the liquid, the foam density is given by

$$\phi = (1-H)\rho_c$$

where ρ_c = liquid density.

Thus, the bubble terminal velocity may be predicted from foam-density measurements by the relationship,

$$V_t = \left(\frac{F}{A}\right)\left(\frac{\rho_c}{\rho_c-\varphi}\right) \qquad \ldots.(39)$$

and from equations 39, 37 and 33 we find

$$C_d = \frac{2.52}{\left(\frac{F}{A}\right)}\left(\frac{\rho_c-\varphi}{\rho_c}\right) \qquad \ldots.(40)$$

Table 2 shows some experimental foam density measurements made at the University of Michigan,[23] with a bubble cap plate for the system air-water (ρ_c = 1; 162 slots; superficial area = 0.615 ft^2).

Drag coefficients calculated, assuming no leakage of gas through the bubble streams, by means of Equation 38 are compared with those deduced from the foam densities by means of Equation 40.

Table 2

Superficial Gas Velocity $\left(\frac{F}{A}\right)$ (ft/sec.)	Volumetric gas flow rate per orifice (F) (ft^3/sec.)	Volumetric fractional gas hold-up $(1-\varphi)$ or (H)	Cd from Equ. 38	Cd from Equ. 40
½	0.0019	0.22	2.48	1.11
1	0.0038	0.40	1.98	1.01
1½	0.0057	0.46	1.72	0.77
2	0.0076	0.54	1.57	0.68
2½	0.0095	0.56	1.45	0.56
3	0.0114	0.60	1.37	0.50
3½	0.0133	0.63	1.30	0.45
4	0.0152	0.65	1.24	0.41
4½	0.0171	0.67	1.19	0.38
5	0.0190	0.69	1.15	0.35

Note that F varies from 0.114 to 1.14 cfm.

The large discrepancy between the drag coefficients deduced by the two methods is a clear indication of the existence of gas bubble leakage, a phenomenon which has been photographically observed by Spells[24] and used by Bakowski[25] to develop equations for Murphree plate efficiencies by means of an idealised model in which channelling rather than bubbling is visualised.

It may be seen that the drag coefficients deduced from foam density measurements are very approximately given by:

$$C_d = \frac{0.308}{F^{\frac{1}{4}}} - 1 \qquad \ldots.(41)$$

where the correction factor -1 introduced into equation 38 accounts for gas bubble leakage. It is instructive to estimate the amount of gas leaking through bubble streams, in the following manner:

Suppose a fraction α of the gas rises as bubbles and $(1-\alpha)$ leaks through the bubble chain.

Then $V_t = \frac{\alpha F}{A(1-\varphi)}$

and $Cd = \frac{2.52(1-\varphi)}{\alpha\left(\frac{F}{A}\right)}$ from Equations 37 and 33.

Moreover from equations 37 and 27

$$Cd = \frac{0.308}{(\alpha F)^{\frac{1}{4}}}$$

and equating the last two equations we obtain,

$$\alpha = \left[\frac{8.15(1-\varphi).A}{\left(\frac{F}{m}\right)^{\frac{1}{4}}m}\right]^{\frac{8}{7}} \qquad \ldots.(42)$$

where A = cross-sectional area of plate.
m = number of slots or orifices in plate.
F = gas flow rate in cu. ft/sec.

From the foam density measurements reported in the previous Table α may be calculated.

Table 3

Superficial gas velocity (F/A) (ft/sec.)	Volumetric flow rate per orifice (F) (ft^3/sec.)	Volumetric fractional gas hold-up $(1-\varphi)$ or (H)	Leakage $(1-\alpha)\times 100$ (%)
½	0.0019	0.22	71
1	0.0038	0.40	64
1½	0.0057	0.46	70
2	0.0076	0.54	72
2½	0.0095	0.56	76
3	0.0114	0.60	78
3½	0.0133	0.63	80
4	0.0152	0.65	81
4½	0.0171	0.67	83
5	0.0190	0.69	84

For data given in Table 3, chain bubbling would be expected over the whole range of conditions reported ($F > 0.1$ cfm).

It is interesting to note that the leakage remains fairly constant at just over 70% as the gas rate is increased. When however, the foam density reaches a value of 0.4 ($H = 0.6$) close packing in both a vertical and horizontal direction would be anticipated (closest packing of equal spheres). Little further bubble expansion is now possible and as shown in the above table the foam density is almost constant while the leakage increases as the gas flow rate rises.

It has been pointed out by the author[16] that this increased leakage on close packing is probably associated with a marked increase in the pressure drop and a sudden increase in entrainment.

It appears likely therefore that gas-liquid plate contactors are not normally operated at foam densities less than about $0.4\rho_c$ because of the entrainment limitation. This means that such equipment is operated in the region of almost constant bubble leakage (α = constant).

Calculation of Interfacial Area

If this is in fact the case, the calculation of the interfacial contact area on plate contactors becomes a simple matter.

Thus if m = the number of holes or slots in the plate,

the interfacial area per ft of foam is given by πDm and the area per unit volume of foam by:

$$a = \frac{\pi Dm}{A}.$$ Solving for D by Equation 27, we obtain

$$a = 1.51 \left(\frac{m}{A}\right)^{\frac{3}{5}} \left(\frac{F}{A}\right)^{\frac{1}{5}} \alpha^{\frac{1}{5}} (\text{ft.}^{-1}) \quad \ldots.(43)$$

If α is approximately equal to 0.3 (see Table 3)

$$a = \left(\frac{m}{A}\right)^{\frac{3}{5}} \left(\frac{F}{A}\right)^{\frac{1}{5}} \text{ft}^{-1} \quad \ldots.(44)$$

showing that the interfacial contact area is simply related to the number of orifices per unit area of plate and the superficial gas velocity. (F/A is in ft/sec.).

Work now being planned at the Chemical Research Laboratory is aimed at testing some of the above conclusions, based as they are at the present time on slender evidence, by the light scattering technique for the direct measurement of a.

Mechanical Agitation

The foregoing remarks particularly apply to gas-liquid contacting on plates where the superficial vapour or gas velocity is high and the foam density low. Those conditions do not apply to fermentation equipment in which gas is dispersed, by mechanical agitation of the liquid phase in large tanks and in which the superficial gas velocity is low and the foam density high.

From careful measurements of the gas hold-up or foam density Rushton *et al*[26] find for the air-water system using a turbine impeller,

$$H = \frac{V_s}{V_l} = c \left(\frac{P}{v}\right)^{0.47} (V_s)^{0.53} \quad \ldots.(45)$$

where c is a constant (1.26 to 1.65).
P is the power input to the impeller.
v is the volume of tank contents.

If now we assume that the bubble rising velocity is expressible as:

$$Cd = 18.5\ Re^{-0.6}$$

as found by Allen[27] for gas bubbles ($2 < Re < 200$)
then $V_t \propto D^{1.14}$
and incorporating this result into equation 45 above, we find:

$$D \propto \left(\frac{V_s}{\left(\frac{P}{v}\right)}\right)^{0.41} \quad \ldots.(46)$$

This result agrees with the analysis previously outlined and expressed in Equation 23, to the effect that the bubble or drop diameter is proportional to the $-2/5$ power of the power input per unit volume of tank contents. Moreover the interfacial area per unit volume is given from above by:

$$a = \frac{6H}{D} \propto \left(\frac{P}{v}\right)^{0.88} V_s^{0.12} \quad \ldots.(47)$$

The latter equation demonstrates the importance of power dissipation in securing good contacting and shows the very minor effect which the gas velocity has in this connection.

In experiments on the rate of solution of oxygen in agitated sodium sulphite solutions, Cooper *et al*[28] finds for this liquid phase resistance controlling system:

$$Ka \propto \left(\frac{P}{v}\right) V_s^{0.67} \quad \ldots.(48)$$

where K is the mass-transfer coefficient.

Combining the last two equations we obtain the result:

$$K \propto \left(\frac{P}{v}\right)^{0.12} V_s^{0.55} \quad \ldots.(49)$$

showing a perhaps unexpectedly small dependence of the liquid film resistance on the power input.

This result however receives some support from the work of Hixson and Baum[29] and Mack and Marriner.[30] These workers measured the rate of solution of suspended solids in agitated liquids (liquid phase resistance controlling) and find that $K \propto N^{0.6}$ where N is the speed in rpm of the agitator.

In the region of fully developed turbulence (constant power number) investigated by Rushton[26] and Cooper[28] (Equations 45 and 48 above), the power input is proportional to the cube of the agitator speed, *i.e.*, $\left(\frac{P}{v}\right) \propto N^3$ or $K \propto \left(\frac{P}{v}\right)^{0.2}$

Although the liquid-gas and liquid-solid systems are not strictly comparable, the predicted small effect of the power input on the liquid film resistance appears to be confirmed.

Action of the Agitator

Many problems remain to be solved before an analytical approach to the design of fermenters will be possible. In particular, the rapid decrease in power dissipation with gas hold-up shows that the discharge capacity of the agitator is seriously affected by gas dispersion. The reasons for the spectacular decrease in power dissipation on gas dispersion are not understood. It is quite clear however that the decrease in mean density of the mixed fluids cannot be held responsible, as a decrease in mean density of 5% has been observed to reduce the power consumption to as little as $\frac{1}{4}$ of its value in the unaerated condition. The power consumption is normally directly proportional to the fluid density. The pumping capacity of centrifugal pumps is of course similarly affected in an adverse way by the presence of small amounts of gas. It seems probable that gas would accumulate at the "eye" of the dispenser because of the vortex field set up in this region. This may result in boundary layer separation at an early stage as fluid moves over the hydrofoils and consequent loss in power dissipation. Kalinske[54] correlated data on power dissipation in unaerated and aerated water using a vaned disc impeller by means of the equation:

$$\frac{P_{No}\ with\ air}{P_{No}\ without\ air} = 1 - 1.62\sqrt{\frac{F}{NL^3}}$$

where F is the volumetric air rate.
N is the impeller speed in, for example, rpm.
and L is the impeller diameter,

Oyama & Endoh[55] plotted $\frac{P_{No}\ with\ air}{P_{No}\ without\ air}$ against F/NT^3 where T is the tank diameter and give a number of curves referring to the use of paddles, vaned discs and flat bladed turbines which reveal the fact that flat-bladed turbines give the best characteristics. A large number of blades on the impeller is advantageous and the type of gas sparger is unimportant.

Furthermore, the fermentation industry is normally concerned with non-Newtonian fluids and the power characteristics of agitators in this type of medium have so

far not been reported. For most non-Newtonian fluids the apparent viscosity decreases with the rate of shear or agitation level. Although the power consumption is independent of viscosity in the region of fully developed turbulence, the critical Reynolds number to be attained for this condition is illusive since as the agitator tip speed increases, the viscosity changes. Metzner[31] has indicated a possible and attractive approach to the latter problem by defining a generalised Reynolds number which contains two rheological constants. Use of the generalised Reynolds number appears to correlate pressure drop data for pipe flow of non-Newtonian fluids and may be equally useful in correlating Power numbers.

Falling or Rising Velocity of Liquid Drops

In a recent paper Hu and Kintner[5] have succeeded in correlating the terminal velocities of fall of single drops of ten different organic liquids in a water field.

This correlation which represents a considerable advance on previous work must still be used with caution since the effect of continuous phase viscosity was not considered. Thus in studies on the rate of fall of mercury and bromobenzene drops in glycerol-water fields of varying viscosity Korchinski and Calderbank[32] find appreciable departures from the Hu-Kintner correlation, as shown in Fig. 1.

Usually in practice, liquid drops are caused to rise or fall through the continuous phase in a packed column. Pratt[33] has correlated liquid drop sizes in packed columns and discussed the condition of hindered fall or rise in terms of an effective drag coefficient.

Continuous Phase Resistance

In general the over-all resistance to mass transfer between dispersed and continuous phases will be the resultant of the two separate resistances in each phase. The heat and mass transfer coefficients obtaining when fluid flows over a spherical solid body, which itself offers no resistance, have been fairly thoroughly investigated and the established correlations such as that of Froessling have been discussed by Sherwood and Pigford.[34]

In experiments on the rate of solution of gas bubbles, Garner[35] concludes, that for small bubbles which behave as rigid spheres, the Frössling correlation[36] holds. For larger bubbles which undergo internal circulation, the mass transfer coefficients are about twice the value predicted by the Frössling equation and in fact fairly closely obey the semi-theoretical equation of Higbie.[37]

Using the nomenclature:

Sc = Schmidt no. $= \mu_c/\rho_c D_M$

Sh = Sherwood no. $= KD/D_M$

Re = Reynolds no. $= DV\ \rho_c/\mu_c$

where K is the mass transfer coefficient, D the equivalent sphere diameter, D_M the molecular diffusivity and V the relative velocity between sphere and continuous phase, we have

Frössling Equation:

$$Sh = 2.0 + 0.6\ (Sc)^{\frac{1}{3}}\ \ (Re)^{\frac{1}{2}} \qquad \ldots\ (50)$$

Higbie Equation:

$$Sh = 1.13\ (Sc)^{\frac{1}{3}}\ (\mathrm{Re})^{\frac{1}{2}} \qquad \ldots\ (51)$$

The latter equation is based on a model which suggests that elements of the continuous phase fluid are successively exposed to the interface for intervals of time equal to D/V.

In this short interval of time the classical diffusion equation, in the limiting form which applies for short contact times, is assumed to hold. Diffusion into a semi-infinite body is thus the basis of the model, and this requires that $K \propto D_M^{\frac{1}{2}}$ instead $K \propto D_M^{\frac{2}{3}}$ as given by Frössling.

The Higbie equation particularly applies where there is a negligible drag between the two phases and where therefore the relative velocity at the interface is the same as in the bulk. The fact that there is a roughly two-fold difference between the mass transfer coefficients predicted by equations 50 and 51 indicates that the relative velocity at the interface in the case of rigid spheres is about $\frac{1}{4}$ of the main stream relative velocity. Thus Garner's observations on gas bubbles, previously referred to, imply that the onset of internal circulation in the bubble, results in the virtual elimination of drag. This conclusion cannot however be applied to liquid drop behaviour as both Hu and Kintner[5] and Korchinski and Calderbank[32] find that the onset of interval circulation is without measurable effect on the drag coefficient as measured in terminal velocity experiments (see Fig. 2).

Korchinski and Calderbank[32] in experiments on heat transfer between mercury drops (negligible thermal resistance) and aqueous solutions of glycerol find agreement between their results and those reported for heat transfer from solid spheres despite the fact that the mercury drops were known to be in a state of internal circulation. This

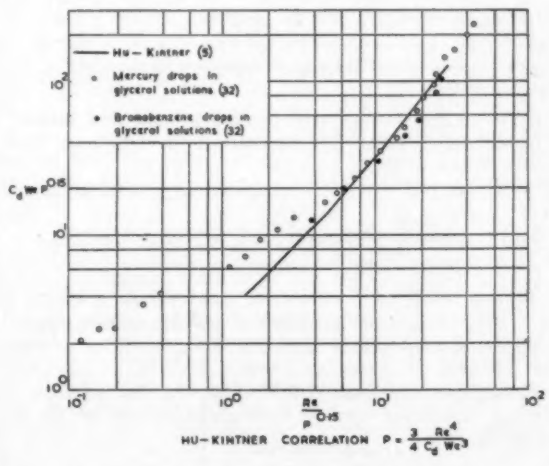

Hu – Kintner (5)
Mercury drops in glycerol solutions (32)
Bromobenzene drops in glycerol solutions (32)
HU–KINTNER CORRELATION

Fig. 1. Departures from Hu-Kintner correlation at high field viscosity.

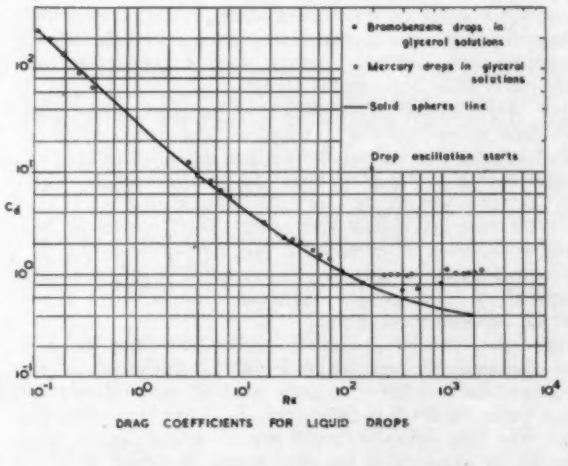

Bromobenzene drops in glycerol solutions
Mercury drops in glycerol solutions
Solid spheres line
Drop oscillation starts
DRAG COEFFICIENTS FOR LIQUID DROPS

Fig. 2. Drag coefficients for liquid drops (bromobenzene and mercury drops in glycerol solutions).

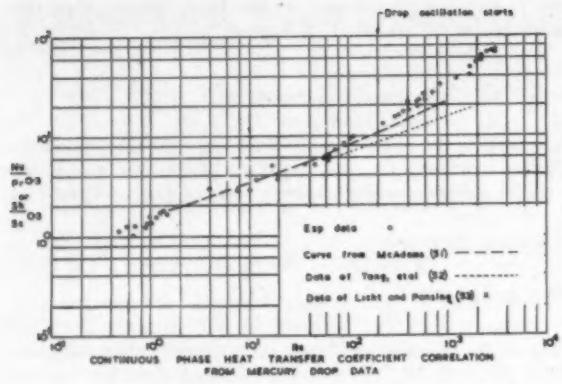

Drop oscillation starts
Exp data
Curve from McAdams (51)
Data of Yang, et al (52)
Data of Licht and Pansing (53)
CONTINUOUS PHASE HEAT TRANSFER COEFFICIENT CORRELATION FROM MERCURY DROP DATA

Fig. 3. Continuous phase heat-transfer coefficients for falling liquid drops (bromobenzene and mercury drops in glycerol solutions).

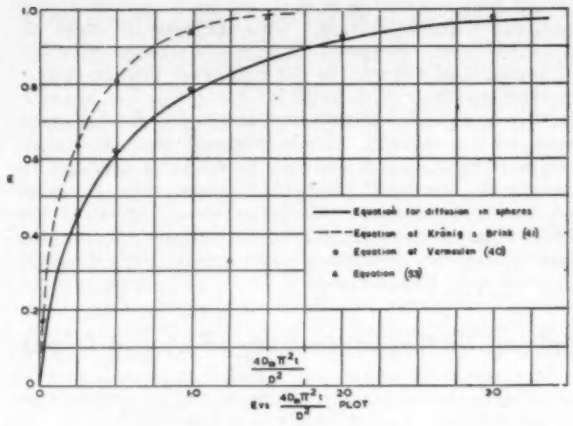


Fig. 4. Comparison of theoretical and empirical equations for diffusion into stagnant and circulating drops.

agreement however no longer held when the drops began to oscillate (see Fig. 3).

Application to Various Systems

It seems reasonable to conclude from this that the Frössling equation holds for mass transfer in the continuous phase to or from liquid drops in both the rigid drop and circulating regimes. When the drop begins to oscillate, as for larger drops, the mass transfer coefficients increase markedly and in an unpredictable manner. An outstanding difficulty is that of defining precisely the regions over which rigid sphere, circulating and oscillating behaviour will be found. Many observers have noted the considerable effect of surface active agents and contaminants in this connection.

Ranz[38] has shown that the Frössling equation, which applies to single spheres, becomes synonymous with the accepted equations for mass transfer in packed beds if due allowance is made for the interstitial fluid velocity in the latter systems.

Thus it appears reasonable to conclude that the equations for packed beds may be used for liquid dispersions also. The correlation of Chu,[39] which applies to packed and fluidised beds, would appear to be most relevant in the above connection since it holds over a wide range of voidage corresponding to the range of dispersed phase hold-up normally met with in practice. The above remarks apply to flow systems with a clearly defined relative velocity between the phases.

In agitated systems, the data are even more sparse than for flow systems and at present we are forced to draw what conclusions we can from experiments with dispersed solids such as those of Hixson and Baum,[29] and the work of Cooper *et al*[28] on the rate of dissolution of oxygen.

With both gas-liquid and liquid-liquid systems it has frequently been observed that the rate of mass-transfer is considerably greater at the injection and coalescing sections of the dispersion equipment than is found in the period between these events.

For two immiscible liquid systems between which a third mutually soluble solute is being transferred, as for example the transfer of organic acids in aqueous solution into water insoluble organic solvents, it has been observed that the mass-transfer coefficient is much higher than would be expected from experiments in which a solid-liquid interface was present. As a possible explanation of this phenomenon it has been suggested that the heat of solution liberated at the liquid-liquid interface may have a considerable influence on the physical properties in this confined region.

The last two complicating factors are noted to draw attention to the fact that when the dispersed phase is a fluid, the problem of predicting mass-transfer coefficients is considerably more difficult than is the case for solid dispersions.

Dispersed Phase Resistance

The use of the film concept as a model for the resistance within the units of the dispersed phase although attractively simple is undoubtedly naïve.

The equation for diffusion into a static sphere may be expressed as either a converging infinite Fourier series of as a diverging series obtained by the Laplace transform method. Although limiting forms of these solutions such as those obtaining at very short or very long contact times are fairly simple, the general solution is unwieldy. Vermeulen[40] has shown however that the empirical equation

$$E = \left[1 - e^{\frac{-4D_M\pi^2 t}{D^2}}\right]^{\frac{1}{2}}$$

fits the analytical solution with considerable accuracy,

$$E = \frac{C_t - C_o}{C\infty - C_o} = \text{fractional approach to equilibrium,}$$

C_t = integral mean concentration in sphere at time t,
C_0 = initial uniform concentration in sphere at time zero,
$C\infty$ = integral mean concentration in sphere at equilibrium ($t \quad \infty$),
D_M = molecular diffusivity,
t = contact time.

Krönig and Brink[41] consider the case where the sphere is in a state of internal circulation, and by making several simplifying assumptions derive a complex series solution for this case.

Korchinski and Calderbank[32] find that the solution of Krönig and Brink can be accurately represented by the empirical form.

$$E = \left[1 - e^{-2.25\left(\frac{4D_M\pi^2 t}{D^2}\right)}\right]^{\frac{1}{2}} \qquad \ldots.(53)$$

This result immediately implies that the effective diffusivity for mass transfer within circulating liquid drops is 2.25 times the molecular diffusivity.

The reported work both on heat and mass transfer within single falling or rising drops has been recalculated and the dispersed phase resistance expressed as effective thermal or mass diffusivities in Table 4.

Table 4

Ref.	Drop Reynolds number	System	Effective Diffusivity (De) ÷ Molecular Diffusivity (D_M)
43	1780	Heat-transfer: water–benzene	1.72
	1740		1.91
	1700		2.05
	1500		1.65 Average =2.0
	850		1.61
	730		2.32
	810		2.44
44	1950	Heat-transfer: kerosense–water	2.3
44	1650	Heat-transfer: xylene–water	2.3
32	73	Heat-transfer: bromobenzene–aqueous glycerol	2.2
	74		2.4
	80		2.6
	83		2.3
	82		3.1
	77.5		2.6
	74		2.2 Average =2.4
	31.3		1.8
	11.3		2.5
	11.8		2.3
	12.0		2.9
	12.0		2.8
	10.2		1.9
	10.8		2.3
45	95	Mass-transfer: isobutanol to water	2.2
	151		2.3 =2.2 Average
	190		2.1

In most cases allowance had to be made for the finite resistance in the continuous phase and this was derived from the Frössling[36] or Kramers[42] equation for mass and heat-transfer respectively. An extrapolation procedure had sometimes to be employed to allow for the enhanced rate of transfer at the injection point. The average of all of the results reported in the last column of Table 4 is $D_e/D_M = 2.3$ in agreement with the value of 2.25 predicted in Equation 53.

Further experiments by Korchinski and Calderbank[32] showed that the value of D_e/D_M became considerably greater than 2.3 for all cases where (*a*) drop oscillation was apparent and (*b*) a third component was being transferred between the dispersed and continuous phases. This is shown in Tables 5 and 6.

Table 5. Effect of third component transfer

Ref.	Drops Reynolds Number	System	D_eD_M
46	290	Acetic acid from benzene to water	9
	450		10
	690		12
47	270	Acetic acid from nitrobenzene to water	6.6
	480		21
	680		28

Table 6. Effect of drop oscillation

Ref.	Drops Reynolds Number	System	D_eD_M
48		CO_2 into water drops	20
32	338	Heat-transfer: bromobenzene–water	8.0
	338		6.7
	350		7.8
	315		8.9
	340		8.7
	340		6.7
	385		6.6
	530		8.7
	620		11.8
	465		12.0
	430		10.1
	460		9.0
	450		9.3
	440		7.0

It was noted that no decay in the effective thermal or mass diffusivity took place with column length or time of fall so that the effective diffusivity seems to be a satisfactory means of expressing transfer rates for falling or rising drops. No satisfactory way of predetermining the point at which drop oscillation commences is apparent, and Table 6 contains data for which drop oscillation was actually observed to occur.

Overall Resistance to Mass Transfer

Amunsden[49] has demonstrated a strict mathematical approach to solving the complicated problem of the summation of resistances expressed as a mass-transfer coefficient for the continuous phase and an effective diffusivity for the dispersed phase. The over-all solution for countercurrent column performance with given operating and equilibrium lines, which are not necessarily linear, is also given in the above paper.

Other workers have sought approximate solutions by adopting the equivalent film concept for diffusion within the sphere.[40, 50] Strictly speaking the latter concept is only valid if equilibrium and operating lines are very close to each other, i.e., for small "upsets". For the latter condition, the diffusion equation approaches the form:

$$Ka = 40D_e/D^2 \quad \ldots\ (54)$$

in which K is the mass transfer coefficient based on the linear driving potential of the familiar film theory and

$$a = 6/D$$

For difficult separations where many theoretical plates are employed the above approximation is most nearly true.

Glueckauf[50] on the basis of semi-empirical reasoning developed a similar equation to the above.
Glueckauf derives:

$$Ka = \frac{60\,De}{D^2} \quad \ldots\ (55)$$

Equations 32 and 33 have been used in the analysis of ion-exchange kinetics, but it is not yet apparent which more nearly holds true.

Conclusions

This paper covers one small though important aspect of chemical engineering. It describes the progress in the

analytical approach to a particular problem. The spectacular success of the empirical correlative approach in the early days of chemical engineering has now been largely succeeded by a much more difficult analytical approach, the fruits of which have yet to be realised. If they are to be realised, and it is largely a matter of faith that they will be, it is clearly desirable that fundamental research on chemical engineering problems be encouraged. This review emphasises the considerable gaps in our knowledge of the mechanism of one of the most common industrial operations. A similar situation is apparent over the whole field of chemical engineering.

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REFERENCES

Note. Bracketed figures on the graphs (Figs 1-4) correspond to the number in this list of references.

[1] Hu, S., and Kintner, R. C., *A.I.Ch.E. Journal*, March, 1955, **42**.
[2] Hughes, R. R. *et al. Chem. Engng. Progr.*, 1955, **51**, 557.
[3] Leibson, I. *et al.* Houston meeting of A.I.Ch.E. (May, 1955) and private communication.
[4] Davidson, L. Ph.D. Thesis, Columbia University, 1951.
[5] Garber, H. J. Preprint 43, Detroit meeting of A.I.Ch.E., Nov., 1955.
[6] Calderbank, P. H. *Trans. Instn. Chem. Engrs.*, (in press).
[7] Panasenkov, N. J. *J. Tech. Phys.*, Moscow, 1951, **21**, 160.
[8] Marshall, W. R. *Chem. Engng. Progr.* Monograph Series, 1954, No. 2. Vol. 50.
[9] Hayworth, C. B. and Treybal, R. E., *Ind. Eng. Chem.*, 1950, **42**, 1174.
[10] Garber, H. J. and Peebles, F. N *Chem. Engng. Progr.*, 1953, **49**, 88.
[11] Garner, F. H. and Hammerton, D. *Chem. Engng. Science*, 1954, **3**, 1.
[12] Haberman, W. L. and Morton, R. K. Report 802, U.S. Navy Dept., Taylor Model Basin, Washington, D.C.
[13] Second Annual Report from University of Michigan on A.I.Ch.E.-sponsored plate-efficiency programme (1954).
[14] Spells, K. E. and Bakowski, S. *Trans. Instn. Chem. Engrs.*, London, 1950, **28**, 35.
[15] Bakowski, S. *Chem. Engng. Science*, 1952, **1**, 266.
[16] Rushton, H. H. *et al. Ind. Eng. Chem.*, 1954, **36**, 517.
[17] Allen, H. S. *Phil. Mag.*, 1900, **50**, 323.
[18] Cooper, C. M. *et al. Ind. Eng. Chem.*, 1944, **36**, 504.
[19] Hixson, A. W. and Baum, S. J. *Ind. Engng. Chem.*, 1941, **33**, 478 (1941); 1942, **34**, 194; 1944, **36**, 528.
[20] Mack, D. E. and Marriner, R. A. *Chem. Engng. Progr.*, 1949, **45**, 545.
[21] Metzner, A. B., and Otto, R. E. University of Deleware, Newark, Delaware (Private communication).
[22] Korchinski, I. J. O. and Calderbank, P. H. *Chem. Eng. Science* (in press).
[23] Pratt, H. R. C. and Gayler, R. *Trans. Instn. Chem. Engrs.*, 1953, **31**, 69.
[24] Sherwood, T. K. and Pigford, R. L. "Adsorption and Extraction," Chap. III. McGraw-Hill, 1952.
[25] Garner, F. H. and Hammerton, D. Symposium on Gas Absorption, Institution of Chemical Engineers, 1954.
[26] Frössling, N. Beitr. Geophys., 1938, **52**, 170.
[27] Higbie, R. *Trans. Amer. Inst. Chem. Engrs.*, 1935, **31**, 365.
[28] Ranz, W. E. *Chem. Engng. Progr.*, 1952, **48**, 247.
[29] Chin Chu, J. *Chem. Engng. Progr.*, 1953, **49**, 141.
[30] Vermeulen, T. *Ind. Eng. Chem.*, 1953, **45**, 1664.
[31] Krönig, R. and Brink, J. C., *App. Sci. Res.*, A-2, **142**, (1950).
[32] Kramers, H. *Physica*, 1946, **12**, 61.
[33] Garwin, L. and Smith, B. D. *Chem. Engng. Progr.*, 1953, **49**, 591.
[34] McDougall and Myers. Preprint 49, Detroit meeting of A.I.Ch.E., Nov., 1955.
[35] Heertjes, P. M. *et al. Chem. Engng. Science*, 1954, **3**, 122.
[36] Sherwood, T. K. *et al. Ind. Eng. Chem.*, 1939, **31**, 1144.
[37] Garner, F. H. and Skelland, A. H. P. *Ind. Eng. Chem.*, 1954, **46**, 1255.
[38] Hughes, R. R. and Gilliland, E. R. Washington meeting of A.I.Ch.E., Mar., 1954, and private communication.
[39] Amundsen, N. R. *Ind. Eng. Chem.*, 1956, **48**, 26.
[40] Glueckauf, E. *Trans. Faraday Soc.*, 1955, **51**, 1540.
[41] McAdams, W. H. "Heat Transmission," p. 267. 3 ed. McGraw-Hill, 1954.
[42] Tang, Y. S., Duncan, J. M. and Schweyer, H. E. NACA Tech. Note 2867, Washington D.C., 1953.
[43] Licht, W. and Pansing, W. F. *Ind. Eng. Chem.*, 1953, **45**, 1885.
[44] Kalinske, A. A. *Sewage Industr. Wastes*, 1955, **27**, 572.
[45] Oyama, Y. and Endoh, H. *Chem. Eng. (Japan)*, 1955, **19**, 2.

Bulk Delivery of Dried Vacuum Salt

THE Salt Division of I.C.I. has developed a new system of bulk handling for pure dried vacuum salt and has established a delivery service by which salt, carried in special vehicles, is pumped by compressed air direct from the vehicle into containers on the customer's premises.

Although all grades of salt have in the past been despatched in bulk, it was not always possible to discharge the delivery vehicles conveniently and economically. This was particularly true of dried vacuum salt which, because of its free-running nature, had to be sent in enclosed bottom-discharge hopper vehicles. Most users took dried salt in bags in order to avoid having to provide, for their relatively small tonnages, the underground bins and elevators needed for bottom-discharge vehicles.

One of the new vehicles by which the Salt Division of I.C.I. is now delivering dried vacuum salt in bulk. The photograph shows an operator on a factory site connecting an intake pipe through which the salt will be discharged by compressed air.

Conveyors and elevators are unnecessary as the salt is discharged by means of compressed air. Thus the consumer is enabled by the new service to locate a silo or saturator at the most convenient point for his process and to have salt delivered directly into it. Further advantages are that the buyer, in addition to saving the cost of bags and of their handling within his works, economises on storage space.

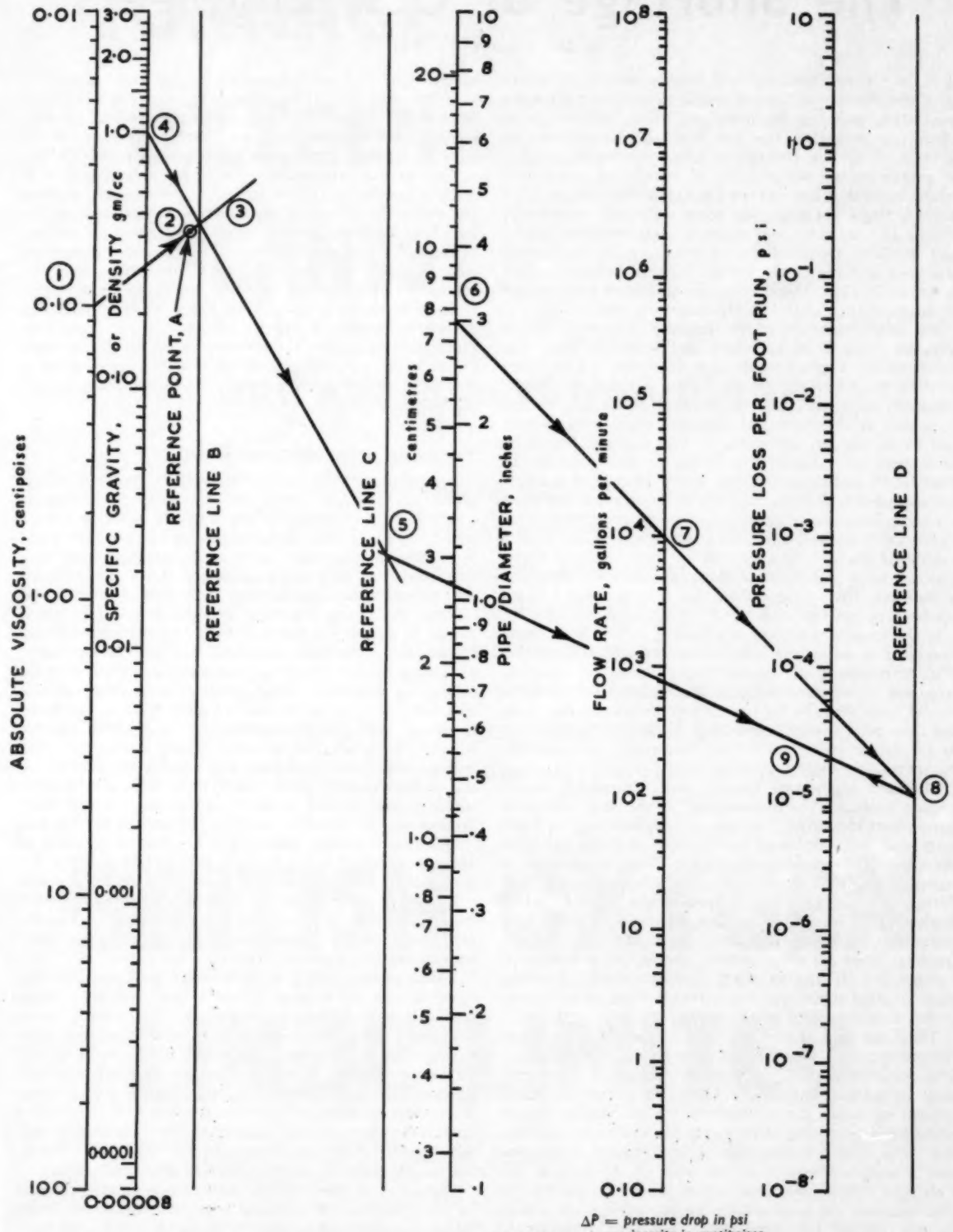
The type of special delivery vehicle which is being operated by I.C.I. Salt Division consists of a Leyland "Octopus" chassis on which are mounted light alloy pressure vessels manufactured by Marston Excelsior Ltd., Wolverhampton. A compressor on the chassis provides the compressed air needed to discharge the load. The vessels on the road vehicle are filled by gravity from overhead salt silos at the Salt Division's works, and the hatches are then sealed with rubber-lined lids to prevent contamination and moisture absorption during transit.

The salt is discharged from the vehicle by means of compressed air through 4 in. bore armoured hose pipe, which is carried on the vehicle, and is connected to the intake pipe on the customer's premises. The relatively coarse particle size and high density of salt made it necessary to modify standard pneumatic handling equipment. The salt can be carried to a height of 40 ft and over a horizontal distance of 30 ft at a rate of 20 tons per hour. The equipment can discharge to a greater height or distance, but possibly at a lower rate.

NOMOGRAM No. 4

The pressure loss per foot run of pipe with fluid (gas or liquid) in turbulent flow

EXAMPLE: diameter = 3 in.; flow rate = 10,000 gpm; specific gravity = 1; viscosity = 0.10 cp
∴ Pressure loss (by nomogram) = 2.05×10^{-5} psi
" " (by calculation) = 2.00×10^{-5} psi



This nomogram is based upon the following equation: $\Delta P = (2.567 \times 10^{-10}) \frac{\mu^{0.16} Q^{1.84}}{S^{1.16} d^{4.84}}$

ΔP = pressure drop in psi
μ = viscosity in centipoises
Q = rate of flow in gpm
S = specific gravity
d = diameter of pipe in inches

AMERICAN LETTER

The Shortage of U.S. Engineers

by Dr. Lincoln T. Work

IN the United States we have become very much aware of the shortage of trained people to carry out the tasks associated with an economy in which technology is advancing so rapidly. The past fifty years have shown an increase of 70% in elementary school enrolment, roughly in proportion to the increase of population. Secondary school enrolment has increased about fifteen-fold, but that in the colleges has been only about eight-fold. Somewhere around 15% of those who graduate from secondary school now graduate from college; of these, about 7% become engineers and a roughly similar number become trained scientists. In 1955, 23,000 engineers graduated from college to augment the 500,000 in the country's work force.

The changing nature of the economy appears to call for a larger number of engineers and scientists than this. Furthermore, a greater extension of scientific knowledge to all of the American people is being found to pay useful dividends all round. The shortage of adequately trained personnel in chemistry and chemical engineering is very real to us, but any correction of that shortage has to be made with due consideration to the nation's need for all kinds of trained personnel. The heavy demand of industry for engineers is draining teachers of science and engineering away from the universities and secondary schools. One recent study showed that in the case of 93 colleges (with a total of about 5300 engineers on their staffs) 324 new teachers were gained from industry while 495 were lost to industry. These figures show that there is a trend which needs to be put right.

In the secondary schools, the training is similar for those interested in the arts as well as those interested in science. The development of regional high schools of relatively large size for several rural areas (the students are conveyed to and from them by bus) permits of better training along the lines of a student's aptitudes. Technical high schools in the larger cities still further accentuate the scientific background in these formative years.

Chemical engineering training on a reasonably standardised basis has been organised in the state or local-government-supported colleges, engineering schools associated with endowed universities, and the technical institutes. The students study for four years with a curriculum specifically associated with their particular field during the later years of this programme. The American Institute of Chemical Engineers, through its accrediting committee, serves to maintain high standards in this training. There are 85 accredited schools, and a substantial number are striving to reach those standards. Teaching staff, laboratory facilities, and curriculum are all considered in this connection.

There are some exceptions to this four-year day school curriculum, and their significance is worth considering. The "combined plan," offered by Columbia University, may be starting a new trend, making it possible for a student to enjoy the atmosphere of the smaller college while he is preparing to complete his studies in engineering. After careful examination of the collegiate programme and a joint willingness on the part of the college, the Columbia University Engineering School formalises the plan whereby the student takes an appropriate curriculum in this college for three years. He then transfers to Columbia, receiving a bachelor's degree from his college in one year and an engineering degree from Columbia after another year. This scheme is only just beginning, but several colleges are linked to the plan and are already sending some excellent men to Columbia. Another scheme is the co-operative programme practised by Antioch College in Ohio and by Northeastern University in Boston as well as by a number of others. In such a programme, students are paired for alternate semesters at school and on the job. This requires co-operation from an adequate number of industrial firms nearby, but it affords these companies with a chance to select graduates with whom they are acquainted. Though this plan has many points of merit, it has not tended to grow here. Other ways of financing the worthy student in regular schools make it less necessary, and the students themselves want to get through faster. Military training, the desire to start a home, possible continuation into graduate study are all relevant factors in this context.

Training on Industrial Plants

A modification of major character is the field course given to selected graduates by the Massachusetts Institute of Technology where students carry out their studies on plant data. They work and study at one plant for a few months, then move on to another, until they have completed their year's training. It is a well-established programme which supplements their formal studies and initiates the young engineers into the work of industry. Added to all this we find that there is a substantial group of students in the cities who have had little or no college work and are now studying in the evening while working during the day. The college programme is heavy, and it may take seven or eight years of night work to complete. However, with the development of local junior colleges which can handle the first two years' work, this may become still more significant. The evening programme for the master's degree, taking two to three years after college, is also proving of real service in maintaining a broad background and in extending a man's knowledge for his job.

Graduate training, including both the programme of about one year for the master's degree and that for the doctorate, is being extended to meet the need for men who need to face more of the ramifications of today's engineering. Fellowships, teaching positions, and work on government and industrial projects make it possible to earn one's way during this period of training.

Industries are taking a more active part in education. Since it was made clear in court that they may make reasonable financial contributions to the schools, more companies have been making such gifts. Also they offer summer positions to staff members. Within some of the larger companies, there are schools established which function broadly enough to be close to the college area. Now there is being established for the teaching staff a scheme known as the "Lexington Plan" whereby staff members are paired, as students in the "sandwich" courses are, to alternate in teaching and in industrial work.

Out of all of these efforts, there should emerge changes in the education of chemical engineers which will bring better qualified men in reasonable numbers who can meet the needs of this increasingly technological age.

BCE 301 for further information

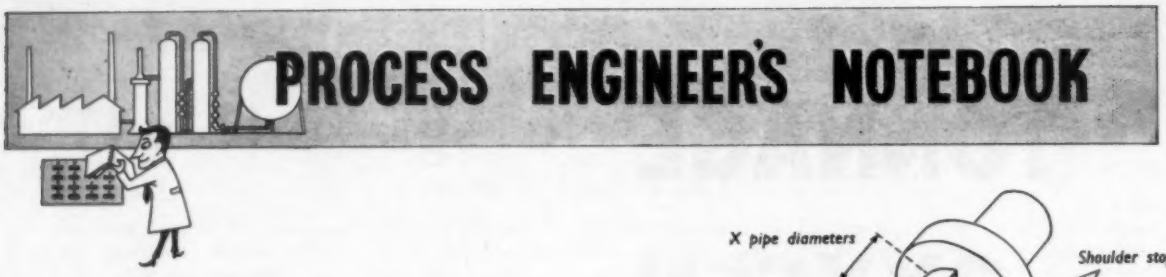
TONNAGE OXYGEN PLANTS

and gas separation plants

British Oxygen Linde offer the combined experience and technical resources of two great companies —The British Oxygen Company Limited and Linde-Gesellschaft— designers and manufacturers of oxygen, nitrogen, and gas separation plants for more than fifty years.

BRITISH OXYGEN LINDE LIMITED

Bridgewater House, St. James's, London, S.W.1

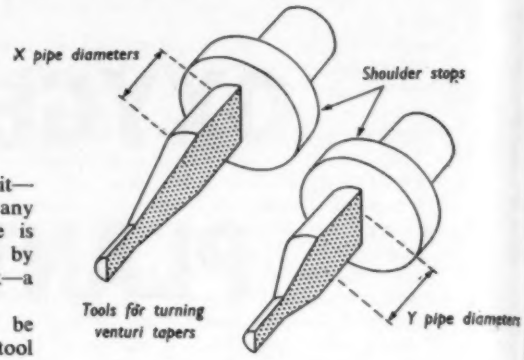


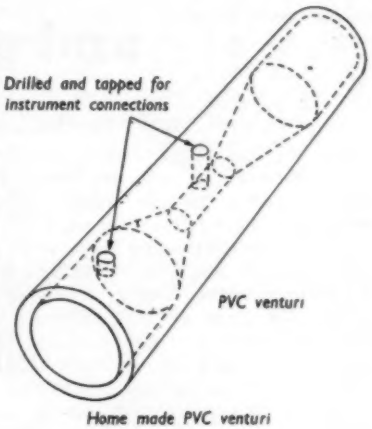
Improvised Flow-Meters

DIFFICULTIES caused by the unavailability of suitable liquid flowmeters, especially if they are the sole item required for completion of a project, can be, to say the least, exasperating. However, it is possible to get round such difficulties and to save expense in cases where the rates of flow to be measured are comparatively small (25 gpm). This is often the case with operations on pilot-plant scale.

Venturi-type bodies can be readily made in any normally equipped workshop from PVC rod, which is available in diameters up to 4 in. The first step is to turn steel, or even brass, male tapers to the dimensions of the required venturi and then to machine half of the taper away in the manner shown in the accompanying diagram. With small tools, it is quite satisfactory to file rather than machine the tool. The rod of PVC is next mounted in the lathe chuck and the improvised forming tool held in the tailstock. The PVC rod is set in motion and the tool forced into it—brutally, one might say—at almost any speed, providing the temperature is kept down. This can be done by feeding water on to the work—a laboratory squirt bottle will do.

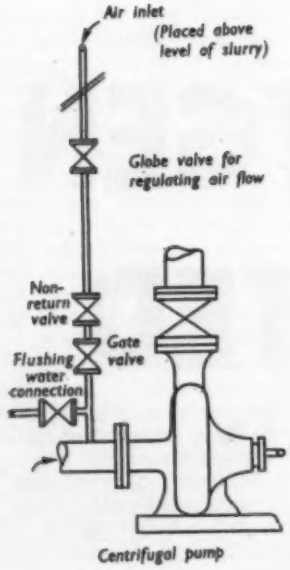
The throat portion should be formed at the taper end of each tool in the manner shown and the cut-away should extend to the shoulder. The length of the larger diameter parallel sections marked "X" and "Y" on the diagram should conform to the relevant British Standard specifications. A pilot hole in the PVC is not necessary. The tappings are readily made liquid tight if a little PVC glue is used in making the joints. The tappings are connected to a suitable manometer or a more refined indicator-recorder if available. The form of the venturi thus achieved will be found to be surprisingly accurate and the results obtained from venturi made for the same tools are in close agreement.





Home made PVC venturi

Flow Control of Centrifugal Pumps Handling Slurries



Centrifugal pump

THE FLOW of a liquid from a centrifugal pump is normally regulated by throttling the delivery by means of a valve. Where slurries are handled this is seldom a satisfactory practice, as it leads to excessive pump wear and to choking by separated solids. One way of avoiding the need to control the flow by a separate valve is to arrange for the pump to be driven at a speed corresponding to the required rate of flow, and this is one reason why centrifugals handling slurries are generally belt-driven. This, however, is a relatively inflexible way of achieving control and may not always meet the requirements of the process.

A method of controlling flow which avoids the use of a valve is shown in the accompanying diagram. In this, a branch carrying a stop-valve, a non-return valve and a regulating valve is added to the flushing water connection. Liquid flow control is obtained by adjusting the globe valve to admit air to the pump suction at a rate sufficient to reduce the pump output to the required amount. The stop-valve is fully opened during the admission of air and is closed when the pump has to be flushed through or loses prime.

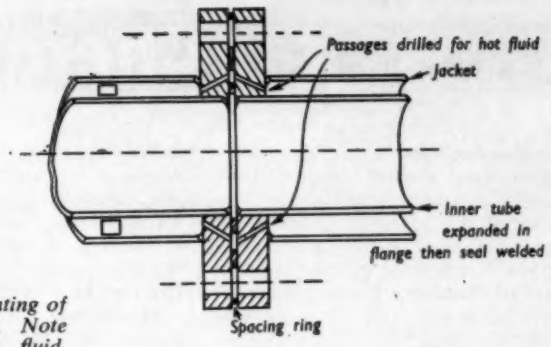
This method of control has advantages where clear liquids such as water are being handled by large centrifugal pumps. In this case the air bleed was used successfully to solve the problem of severe arcing and the consequent wear on the circuit breaker contacts which arose from the method of stopping the pump. This was to throttle the flow in the usual manner, switching off the motor. By reducing the flow by means of the air bleed the motor current may be reduced to a quarter or less of full load and the circuit is then broken without risk of arcing at the contacts.

Method of Jointing Jacketed Pipelines

IT IS customary when a material in a pipeline requires heat to maintain it in a fluid state to heat the line by some system of tracing—or where this is considered to be inadequate to jacket the lines and supply the heating fluid to the jacket. Jacketed lines are also used in low-temperature conveyance of liquefied gases where the jacket space is evacuated so as to provide thermal insulation.

Where jackets are used, normal practice is to terminate them a few inches from the flanged end of a pipe section. The jackets of adjoining sections of pipework have then to have their own connecting pieces of piping looping the flanged joint of the main pipework. Such installations are costly and they suffer from the disadvantage that not all the pipeline is heated or insulated, as the case may be, and they waste space.

One solution to this problem is illustrated in the diagram. It consists basically of making the connection between adjacent jackets through the flanges themselves. The latter are drilled to provide a throughway for the passage of heating fluid, and it is preferable to drill obliquely as shown in order to give sufficient space for the gasket.


Passages drilled for hot fluid
Jacket
Inner tube expanded in flange then seal welded
Spacing ring
Joint for jacketted pipe lines

The method of jointing of jacketed pipelines. Note passages for hot fluid.

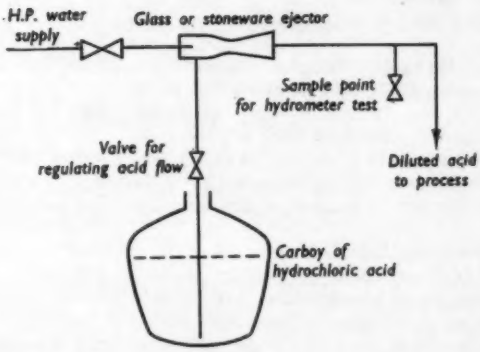
The first step in the fabrication procedure is to weld a series of spacers to the outside surface of the inner pipe, so that its jacket will be supported concentrically with it. The spacers consist of short pieces of rod which are welded lengthwise along the tube in groups of four, equi-spaced around the circumference. For piping supplied in 20 ft lengths or so, about four such sets are adequate, and the spacers nearer the ends of a length of tubing should be located about 3 in. from the back face of a flange. A single flange is then attached to the inner pipe which is expanded in it, leaving a sufficient amount of overlap to seal-weld the flange to the pipe. The remaining flange is fixed to the pipe in the same manner after threading the jacket pipe over its companion. The jackets may then be welded to the flanges.

Jet Pump Dilutes Acid and Pumps to Process

THE PROBLEM to be solved was how to feed hydrochloric acid (delivered to the plant in carboys) in a diluted form to a vessel on which an organic chemical reaction was being carried out. The early stages of the reaction required the presence of excess of alkali, which had subsequently to be slowly neutralised.

Initially, attempts were made to obtain a vessel of corrosion-resistant material or surface. The acid was to be transferred to this vessel, and water added to give the required degree of dilution. The diluted acid was then to be fed by gravity to the reaction vessel.

The fact that such a tank was not readily obtainable, whereas the demand of the product was immediate, led to the abandonment of the dilution tank idea. Instead, the scheme illustrated was adopted. A correctly proportioned jet pump was made, in this instance from glass by a glassblower; the dilution water was the pumping fluid, and the hydrochloric acid in a carboy the fluid to be pumped. A slight adjustment of the valve at the suction is all that is required to give the desired dilution. This is readily tested by means of a hydrometer check or a sample withdrawn from the mainstream at the connection provided.


H.P. water supply
Glass or stoneware ejector
Sample point for hydrometer test
Valve for regulating acid flow
Diluted acid to process
Carboy of hydrochloric acid

The diagram shows the method used to avoid the manual emptying of carboys of hydrochloric acid.

When the contents of the chemical reaction vessel have reached the desired *pH* value, the pumping is interrupted by closing the valve in the water line. Although the jet pump is capable of achieving quite a respectable delivery head, it is not advisable to take advantage of this fact unless a suitably corrosion-resistant non-return valve (e.g. stoneware ball type) can be obtained. This is because with such an arrangement diluted acid will flow back into the carboy, and possibly lead to spillage unless a non-return valve is installed at the pump suction. The best arrangement is one where the jet pump suction line is as close to the carboy as possible and the discharge level is slightly below that of the pump.

It is possible to obtain robust stoneware or PVC jet pump bodies for replacement of the rather fragile glass pump used in this particular case.

The *pH* indicator is also replaceable by a controller which can form part of a closed drop system in which the manually operated water valve is replaced by a motor valve.

The scheme also avoids the handling of concentrated liquid hydrochloric acid.

World of Chemicals

Canadian Potlines

Two new smelter potlines have recently entered production at Aluminium Ltd.'s plants in Quebec and British Columbia. A further potline at Kitimat is scheduled to enter production next December bringing the company's Canadian capacity to a total of 762,000 tons.

Petroleum Congress

The Fifth World Petroleum Congress will be held in New York's new Colesium at Columbus Circle from 30th May to 6th June, 1959.

Australian Minerals

Some £A500,000 will be available for an initial investigation for minerals over one-seventh of Tasmania and the west coast of North of Queensland. The search is being undertaken by Rio Tinto (Australia), and is covered by a six months prospecting licence issued by the Government.

Chilean Copper Plant

A new copper smelter and electrolytic refinery which will have an annual capacity of 30,000 tons a year is being planned by Empresa Nacional de Fundiciones. A site for the new plant has yet to be decided.

U.S. Synthetic "Natural" Rubber

Goodrich Gulf Chemicals Inc. plant for the production of synthetic "natural" rubber is well advanced at the company's site at Avon Lake, Ohio. Plans call for the plant to be in production at the end of this year.

Powdered "Cellofas"

I.C.I. are now in production with Cellofas in powder form from a new plant at Ardeer. The material is expected to be much in demand by the paint and allied industries. Previously available only in fibre form, the powdered Cellofas enables it to be mixed with other dry materials as a mixture.

German Expansion

Farbenfabriken Bayer are to expand their manufacturing activities in Peru. A Bayer subsidiary in Lima will be in production of Moltopren, an all-purpose plastic, towards the end of 1956.

Portuguese Expansion

Amonica Portugues sulphate of ammonia works at Estarreja produced 35,197 tons in 1955, compared to 25,398 tons in 1954. Expansion plans, aiming at a capacity of 70,000 tons a year, continue.

Uniao Fabril de Azoto produced 45,000 tons of sulphate of ammonia in 1955 as against 33,340 tons in 1954. The company are awaiting Government permission to expand their production by new plant of chemical ammonia to 36,000 tons a year and another to 80,000 tons of nitrate of ammonia.

Mexican Resins

Celanese Mexicana, S.A. have announced that they will shortly be in local production of a number of resins used in the manufacture of plastics.

U.K. Refinery Expansion

Esso's Fawley refinery, already the largest in the U.K., is to be further expanded it was recently announced. This new expansion programme will involve some several million pounds. The company's present programme involving £10 million, is nearing completion, while the company's recent decision to enter the petro-chemicals market will involve a further expenditure of a further £9 million. When these schemes are complete the refinery throughput will be about 8 million tons a year.

Pig Food Supplement

Two specialised forms of the antibiotic aureomycin called "Aurofac D" and "Aurofac 10" which were designed for use as food supplements in liquid food for baby pigs and in poultry food respectively, are due to be made available in the U.K. by Lederle Laboratories.

U.K. Cortisone Development

Uclaf, U.K. subsidiary of Uclaf Societe Anonyme, Paris, has been formed to carry on the manufacture of cortisone and other specialised products as made by the parent company in France. A factory for this purpose has been purchased at Stratford.

The chairman will be M. Pierre Beytout who is chairman of Uclaf Societe Anonyme, and the United Kingdom directors will include Mr. Stanley Fergusson Shuttleworth and Mr. Stanley John Baker, chartered accountants and directors of Roussel Laboratories with which the new company will be closely associated. M. Jacques Machizaud, managing director of Roussel Laboratories, will also act as managing director of Uclaf.

Reserpine Synthesised

Reserpine, the valuable alkaloidal principle of *Rauwolfia*, has been synthesised by Prof. R. B. Woodward's team at Harvard University, as reported in the *Journal of the American Chemical Society* (5th May). There is special interest in the possibility of synthetic production of the drug in view of India's recent ban on export of seeds and cuttings of the plant.

Swedish Vitamins

A new factory is to be built by AB Ferrosan's subsidiary company PAS for the production of synthetic vitamins. The factory will be the first of its kind in Sweden and should be in production by mid-1957.

Netherlands Salt

The Netherlands salt industry is to raise its salt ouput from 580,000 to 700,000 tons in the coming year. This is being done to satisfy new demands for salt for use by the chemical industry. A new electric plant for soda production is to be installed at Delfzijl; and a new boiler-house is being built at Hengelo to supply power for the plant.

Zinc Impurities

The American National Bureau of Standards has developed an electrolytic procedure for precise determination of very small amounts of impurities in zinc and zinc-based alloys. The procedure does not require preliminary chemical separations, is relatively fast, and requires little operative attention. It should also be useful for analysis of other metals as well as zinc, particularly non-ferrous alloys.

Canadian Developments

Shell Oil Co. of Canada is to start work soon on a $3 million plant for the production of detergent alkylate (dodecyl benzene), which is the main igredient of household detergent powders.

Another part of the new plant will concentrate on the production of components for high octane gasoline. The main raw material for the process will be by-product gases from the company's nearby refinery. Production is scheduled to start by mid-1957.

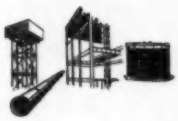
New Iron Ore Plant

Stanton Ironworks Co. Ltd., announce plans for the construction of a new iron ore plant, at an estimated cost of £3,500,000. The new plant, to be situated mainly between Shipley and Ilkeston branch railway in Derbyshire, will take 2-3 years to build.

A SUMMARY OF THE CAPACITIES AND FACILITIES OF THE ENGINEERING COMPANIES FORMING

The HORSELEY Group

HORSELEY BRIDGE & THOMAS PIGGOTT LTD,
HORSELEY WORKS, TIPTON, STAFFS.



One of the oldest Engineering Companies in this country. Equipped to produce all forms of constructional steelwork particularly those of the larger order and including industrial platework. Pioneer manufacturers of Pressed Steel Tanks and large diameter steel mains.

CARTER-HORSELEY (ENGINEERS) LIMITED,
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Specialists in steelwork erection and repair and maintenance of existing plant and structures. Its range covers sheeting and glazing of industrial buildings and fabrication of light structures from works and yards within easy reach of all parts of the United Kingdom.

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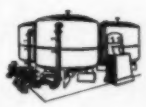

Manufacturers of Water and Effluent Treatment Plant, Water Softening Plant and Filtration Plant for all industrial processes.

RAILWAY MINE & PLANTATION EQUIPMENT LTD,
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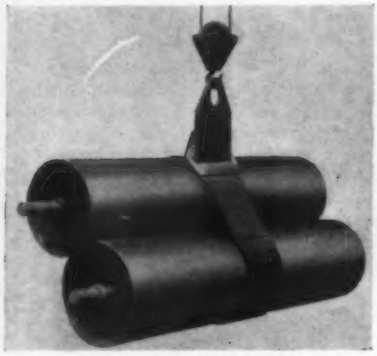
This Company handles all Export Selling for the Group. Agents in all principal territories of the world and touring representatives, based on London, permit very close liasion between overseas buyers and the technical departments of the Group.

HORSELEY GROUP

The services rendered by the Group are wide and comprehensive in their scope and closely co-operative in their functioning. This element of flexibility forms the keynote of the organisation, further detailed information about which is available on request, from Central Headquarters, Horseley Works, Tipton, Staffs.

PLANT EQUIPMENT NEWS



Wire Belt Sling

The British Wedge Wire Co., has developed a sling made from wire belting. Being fully articulated there is no flexure of the wires, giving longer life. In addition the width of the slings gives a greater load carrying capacity, less chance of slipping and because of the greater area there is less chance of damage to the load, very important when lifting hollow tubes. **The British Wedge Wire Co. Ltd., Academy Street, Warrington.**

BCE 328 for further information

Cycol Dust Collector

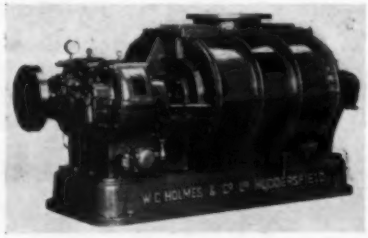
The simple cyclone is probably the most common type of collector in use today, but is equally the most inefficient. A new type of high efficiency dust collector, the "CYCOL", has an operating efficiency of 100% on any particles larger than 30 microns or 80% on 12 micron size.

The unit is very versatile and can be used on many installations and particularly where heavy loadings of the finer dusts occur. It is self-cleaning, requires no maintenance and the fan can generally be mounted on the cleaned air side, thus obviating wear on the fan blade and fan scroll. Any quantity of air can be handled with any number of units in parallel. **P. M. Walker & Co. (Halifax) Ltd., Alexandra Works, Halifax.**

BCE 329 for further information

Gas Pumps

The "H" type range of Holmes-Connersville gas boosters, exhausters and blowers has been redesigned to incorporate improvements in construction and appearance. Amongst the changes are better glands with deeper stuffing boxes, proved to be absolutely gas tight, and larger diameter driving shafts which will put the machines out of the limits of torsional vibration difficulties. In addition, the length of the machines has been reduced by incorporating the outer bearings in the main headplate and gear box casing. **W. C. Holmes and Co. Ltd., Turnbridge, Huddersfield.**

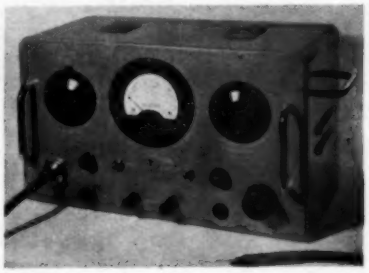


BCE 330 for further information

Proximity Meter

A new type of instrument for the micro-measurement of a wide range of physical variables has been developed and marketed by Fielden Electronics. In principle this electronic "box of tricks" measures minute changes in electrical capacitance on the probe attached to the instrument. Changes in capacitance can be caused by mechanical devices which respond to such things as changes in stress or strain, vibration of a machine, or physical changes such as the dielectric constant of solutions.

The value of the instrument lies in its extreme sensitivity which is such that it can be used to detect mechanical changes of length of 0.00001 in. and correspondingly small changes in physical properties. In addition it is completely stable and can be used to detect changes which take place over periods of months and years, such as the movement of engineering structures.



It has been applied to measurements of deviations from concentricity of fast-turning shafts, variations of thickness of coatings, high-speed vibrations in machines and many other problems. Undoubtedly this device will have numerous applications in all industries. **Fielden Electronics Ltd., Paston Road, Wythenshawe, Manchester 22.**

BCE 331 for further information

Pipe Protection Tapes

An alternative to the painting of pipes subject to corrosion, the new "Speedfix" pipe protection tapes embody new principles both in material and adhesive. They are very tough, have a high insulation resistance, and

are resistant to the action of acids, alkali, fungus and bacteria. Tests indicate a life expectancy of 30 to 40 years underground. The tapes will conform to irregular shapes and surfaces and are not affected by temperature variations. **Industrial Tapes Ltd., Speedfix House, 142/146, Old Street, London, E.C.1.**

BCE 332 for further information

Automatic Feed Control

In continuous processing accurate material feed controllers are necessary. For controlling automatically the rate of feed of material moved by conveyors, Adequate Weighers have produced a machine called a "Feedometer". This machine consists of a weigh table fixed under the conveyor, which is coupled to a graduated weigh beam. The beam is traversed by a counter-balancing weight which, when put out of balance by a variation in

the nature or density of the material on the conveyor, moves a gate over the belt to alter the amount of feed.

In addition to controlling, the weight of material can be totalised and recorded by the Feedometer. The device can be fitted with an electronic slave control for remote operation. Batteries of these machines can be arranged to give a complete mix, each being independently variable as required and all controlled to cut off automatically in the event of insufficient supply to any one of them. **Adequate Weighers Ltd., Bridge Road, Sutton, Surrey.**

BCE 333 for further information

Foam Lubrication

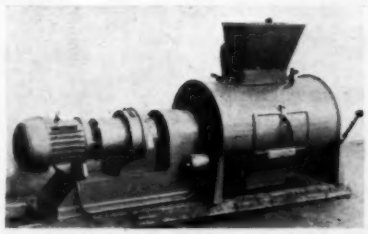
An entirely new conception in lubrication—foam lubrication—has been achieved by the packing of a penetrating oil in an aerosol container. The new "Aerozene" consists of an oil packed into an aerosol container under presure. The lubricant is ejected in a powerful, accurate jet (a 4 in. circle at 7 ft) and produces on the part to be lubricated a highly penetrating graphite foam which has remarkable "wetting out" or "creep" properties. The makers claim that it penetrated heavily encrusted spring shackle bolts in a few minutes and that it is persistant. A companion product is "Rusolvent"—a rust-removing compound also sold in an aerosol pack. Both are non-flammable and are self-sealing after use. **Amber Oils Ltd., 11A Albemarle Street, London, W.1.**

BCE 334 for further information

Mixing Machines

An entirely new type of machine, claimed to be the fastest in the world for mixing pulverised, granulated and fibrous materials, is now being manufactured by the Morton Machine Company. Designed and developed in Germany, these machines range from laboratory models of one quart capacity to production machines with capacity of 5500 gal. It is claimed that with these machines it has been possible to solve for the first time—on a production basis—many complex mixing problems, in many cases reducing from hours to minutes the time taken for the mixing operation.

The Lodige/Morton machine consists of a cylindrical mixing vessel with a set of revolving shovels mounted on arms attached to a shaft. These shovels are double plough shaped and so designed that the mix is thrown upwards and outwards which ensures that the materials are intermingled in space. This method is



entirely different to previous techniques based on forcing the ingredients against each other to achieve the mix. As the shovels pull the mix away from the vessel, there is no possibility of any pressing action which might destroy the particle size of the ingredients. Due to the special shape of these shovels even fibrous materials, which are particularly difficult to handle, can be mixed with a minimum amount of damage. These machines have been successfully used in the plastics industry and a special design has been developed for the production of P.V.C. by the dry powder method. **Morton Machine Co. Ltd., Atlantic Works, Wishaw, Scotland.**

BCE 335 for further information

Expansion Pieces

Expansion in pipe lines caused by variations in temperature and vibration can be taken up by means of an expansion piece. One type on the market is the Rose's pressed steel pieces which work on the principle of steel bellows. The standard bellow is designed to take up $\frac{1}{4}$ to $\frac{7}{8}$ in. and variations greater than this are absorbed by a number of bellows in series. Where more than four bellows are built into one expansion piece an internal sleeve is fitted to ensure smooth flow in the pipe. During installation the bellows are cold sprung half the amount of total expansion so that the movement is through the neutral axis and keeps the metal within the elastic limit. A bellow can be built into a heat exchanger shell to help overcome the problems of expansion met when shell and tubes are of different material. **British Appliances Manufacturing Co. Ltd., Dolly Lane, Leeds 9.**

BCE 336 for further information

Vacuum Distillation Plant

A small vacuum distillation plant, designed to process white spirit for the dry cleaning industry can find a use where small quantities of similar liquids are to be purified. The smallest model will handle 25 gal per hour and the largest 500 gal per hour. The complete unit consists of a vapouriser, condenser, pre-heater, control unit, sieve box, moisture strainer and vertical wet vacuum pump. Heating is by steam at 70 psi which is ample for the system working under 25 in. vacuum. **Hill and Herbert Ltd., 15 Stone Bridge Street, Leicester.**

BCE 337 for further information

Micro-densitometer

Joyce Scientific Instruments have recently put out an improved model of their automatic recording microdensitometer used for measuring the intensity of light absorption. It has applications in X-ray diffraction, microspectrography, cell interferometry, etc. **Joyce Scientific Instruments, Electron House, Simpson Street, Newcastle-on-Tyne, 1.**

BCE 338 for further information

Electric Furnace Elements

High thermal efficiencies and cleanliness have always been big factors in favour of the electric furnace but probably the biggest advantage was the absence of combustion gases in the furnace chamber. However, with the introduction of gas carburising and

PLANT EQUIPMENT NEWS

carbon-nitriding this advantage has been lost and muffles have been resorted to for protecting the heating elements.

To overcome this factor a new type of element called the "Corrtherm" has been developed. It is essentially a sheet of corrugated nickel chromium which entirely covers each wall of the furnace. The advantages for this system are ease of installation and maintenance, as the elements are simply hung from hooks, greater strength and greater length for electrical resistance. Carbon forming on the sheets does not cause leakage as low voltages are used and, in addition, the oxide coating which forms on the surface helps to confine the current to the plate even when covered with soot. In large furnaces, elements can be hung between rows of work to speed heating and give better temperature control. **Electrical Resistance Furnace Co. Ltd., 161 Queen's Road, Weybridge, Surrey.**

BCE 339 for further information

Flexible Wall Chart

The new Movigraph wall chart which enables a picture to be built up of practically every state, process or operation in industry will find many applications in the chemical world. It can be used, for example, to indicate the raw material position, the state and operation of plant or the location of staff. The plastic panel which is the basis of the Movigraph system has 2000 perforations per square foot which will take six major types of signals, each made in 12 colours to give 20,000 signalling combinations. The signals simply plug into the board and are moved as the position changes. Special flow line markers can be used to indicate a chemical process. **Adapta-Charts Ltd., 129 Hammersmith Road, London W.14.**

BCE 340 for further information

Low Cost Spectrometer

A new, low cost, grating type scanning spectrometer is being produced by Jarrel-Ash Co. of America and marketed in this country. It is easily adapted as a flame spectrometer, capable of detecting impurities to one part per billion, and can be used for a wide range of research studies such as analysis of petroleum products for additives, boiler feed water, plating solutions, fertilisers, biological and pharmaceutical materials, etc. The unit measures only 18 in. long, weighs approx. 20 lb and is very easy to use. It is available with one of two electronic systems for either direct recording of intensity or for absorption

measurements. U.K. Agents: **Hilger and Watts Ltd., 98 St. Pancras Way, London. N.W.1; Unicam Instruments (Cambridge) Ltd., Cambridge, England; Johnson, Matthey & Co. Ltd., 73-83 Hatton Garden, London, E.C.1.**

BCE 341 for further information

Particle Size Measurement

Two photo-electric instruments for the measurement of the particle size of powders have been developed by Evans Electroselenium Ltd. They are the "Eel" powder reflectometer and the "Eel" photo-extinction sedimentometer. The powder reflectometer will determine the specific surface of small powders (less than one micron) quickly and accurately. It works on the "tinting strength" method and this instrument can be worked by a comparatively unskilled person under any conditions of site or lighting. The photo-extinction sedimentometer enables particles in the sub-sieve range to be accurately sized. **Evans Electroselenium Ltd., 110/111 Potter Street, Harlow, Essex.**

BCE 342 for further information

Reversible Compressors

When particularly abrasive, corrosive or viscous liquids are to be handled it is common practice to use pressure or vacuum rather than pumps made of costly materials and designs. The compressors manufactured by Lacy-Hulbert can be used as vacuum pumps as well, simply by means of change-over cocks. Thus one of these machines can be used to evacuate a

vessel for filling and then to apply pressure for emptying. Their CYB1 machine incorporating filters and drain traps is suitable to provide vacuum for vacuum filtrations and evaporation. **Lacy-Hulbert and Co. Ltd., Boreas Works, Beddington, Croydon.**

BCE 343 for further information

Mill Scale Remover

A new preparation to remove mill scale from metal surfaces prior to painting has been developed. Named "Skaline", it is simply brushed on to the surface, allowed to stand for 5-10 minutes and then washed off. As soon as the surface is dry, paint can be applied. It does away with the need for shot-blasting and "wire-brushing" it is claimed. **C. & P. Development Co. (London) Ltd., Wiggie Works, Redhill, Surrey.**

BCE 344 for further information

Viking Agitator

Viking have recently announced their latest type of agitator suitable for blending and mixing of liquids, dissolving of solids, suspension of insoluble solids, and improving heat transfer from coils or jackets to liquid. The Viking agitator is designed to provide simple and efficient liquid agitation in the viscosity range up to 300 centipoise. Flange mounted agitators are manufactured in the range 1 to 7½ h.p. In most cases 750 r.p.m. is suitable although speeds of 1000 and 1500 r.p.m. can be supplied. An outstanding feature of the agitator is the neatness of mounting and the absence of external glands and couplings. With the casting projecting into the tank, only the motor projects outside the tank radius. **Viking Engineering Co., 17 Hodge Lane, Salford 5.**

BCE 345 for further information

put it to the test!

These new pumps open up an extensive range of acids, alkalis and slurries to economical pumping. They are constructed in 18/8/3 Stainless Steel for mildly corrosive liquids or in WORTHITE, a super-resistance alloy steel enabling Sulphuric Acid to be pumped with negligible corrosion loss. Also, there is the added advantage of easy interchangeability of the Stuffing Box Packing with two types of Mechanical Seal to suit different processes — plus the embodiment of the well-known Worthington-Simpson "Monobloc" construction which means few parts, lower costs, less wear and easier installation.

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A WIDE RANGE AVAILABLE

WORTHINGTON-SIMPSON LIMITED NEWARK NOTTS

Book Reviews

Chemical Engineering Practice. Vol. I General and II Solid State.

Ed. H. W. Cremer and Trefor Davies

Butterworths Scientific Publications, London, 1956. Vol. I. 494 pp. Vol. II. 632 pp., 85s. per vol.

THESE are the first two volumes of a work which is intended to cover the whole of chemical engineering practice in twelve volumes plus one index volume. The plan of the work has been to subdivide chemical engineering not into unit operations but into a series of physico-chemical principles followed by the application of these principles to process development and plant operation. The editors have sought the advice of the leading chemical engineers in Britain, both in the preparation of the original plan of the work and in its subsequent execution. Each volume will consist of chapters on specific subjects written by experts. The editors' function is to co-ordinate the whole text to avoid unnecessary duplication and to bring a homogeneous work to the public; In this task they have succeeded admirably, if the first two volumes are to be accepted as a measure of the whole work.

Before proceeding to review the particular volumes it may be worthwhile to examine the demand which led up to the preparation of a work of this magnitude, and to enquire as to the value such a work is likely to have, bearing in mind that the total cost of the entire work will be £57. The only previous work of comparable magnitude is that of Euken and Jacob's *Der Chemie Ingenieur* published between 1933 and 1940, and no modern English text has been produced other than the teaching texts of Brown *et al* and Coulson and Richardson. A number of excellent monographs of chemical engineering subjects have been published in recent years—notably those in the McGraw-Hill series—but these do not relate the various branches of chemical engineering one to another, and moreover they are more concerned with advances in theoretical and research studies than with actual practice. There was then an obvious need for an authoritative text, something more than Perry's Handbook, to combine the latest developments of theory with details of the achievements of practice, linking studies in materials of construction, fabrication and corrosion with unit operations and design methods. The production of such a text by any one individual or any single group of individuals was obviously impossible and the editors therefore wisely followed the example set by the editors of the *Science of Petroleum* in calling upon a large number of chemical engineers to write the individual chapters assigned to them.

The introductory volume is devoted to general topics which may be considered common to all chemical engineering operations. The first three chapters deal with: The Origin of Chemical Engineering (Prof. Newitt); The Chemical Engineer (Prof. Garner) and Economics of Production. The next two chapters deal with the Development of an Industrial Process, the first with the preparation of a Mass Balance and the second with the Energy Balance. F. E. Warner has enlarged the subject matter created in "A Problem in Chemical Engineering Design" by Coulson and Warner, and has presented a detailed and readable account of mass and energy balance calculations. It is to be hoped that these chapters will be published separately for student use. Unfortunately a typographical error makes the example of the use of ternary diagrams in solvent extraction more difficult to follow than it need be! Chapters 6-9 deal with various aspects of pilot plant design and operation by Dr. H. Hoog and his colleagues in the Shell organisation. Details are given of a number of pilot plants, and mention is made of almost every conceivable piece of equipment likely to be used in a pilot plant; references to the original literature are provided if further details are needed. This section will be of great value to all development departments. Chapter 11 by G. U. Hopton deals with the Preparation of Flow Diagrams for Full-scale Production, and this again provides a useful student text as well as an authoritative guide for senior workers. Chapter 12 by R. Strickland-Constable deals with Units, Dimensions and Calculations.

Volume II contains fifteen chapters, which are concerned with various aspects of the solid state. An introductory chapter by M. J. P. Musgrave on Fundamental Concepts is followed by five chapters on Metals and Metallic Alloys, a chapter on the Mechanical Properties of Plastics and Glasses and one on Corrosion of Metals. These chapters cover the metallurgical aspect of the solid state. The next chapter deals with Porous Masses, and is followed by chapters on Porous Powder Metallurgy and Powder Metallurgy, and four chapters on the Industrial uses of Porous Masses—The Purification of Coal Gas, Flow in Fuel Beds, Treatment of Water and Sewage, and Transpiration Cooling. The section dealing with Metals and Metallic Alloys includes chapters on Mechanical Properties, Alloy Equilibrium diagrams, Range of Steels, Fatigue in Metals, and Creep in Metals. Sufficient background is given to enable a chemical engineer who is not a metallurgist to obtain information on these subjects, although some of the treatment is a little sketchy. The chapter on Corrosion by F. Wormwell and E. Lloyd Evans is excellent, as is P. Eisenklam's contribution on Porous Masses. The final chapters on Application of Porous Masses in Industry indicate the method by which the editors hope to approach the "practice" of Chemical Engineering, i.e. by individual chapters each devoted to the application of a particular operation or group of operations in a well-developed industrial process.

The books are well produced, adequately indexed and well illustrated. Future volumes in the series will be awaited with interest.

The Non-Ferrous Metal Industry in Europe

Organisation for European Economic Co-operation, OEEC., Paris; H.M.S.O., London; 1956, 92 pp., 7s.

THE Non-ferrous Metals Committee of OEEC has undertaken a survey of the trend of the non-ferrous metals industry in Europe during the year 1954 and the first part of 1955. This book is the report of the Committee. It contains a chapter on aluminium, copper, lead, zinc, tin and nickel and discusses in detail changes in the demand and production of each metal. The demand for non-ferrous metals is rising quickly because of the rapid expansion of metal-using industries such as mechanical and electrical engineering and building. The result of this pressure of demand, together with extraneous circumstances such as strategic stock-piling and strikes has led to rapid fluctuations in some metals, particularly copper. The price of copper almost doubled between January and September, 1955. By comparison, aluminium and nickel prices remained fairly steady because the producers followed a policy of price stability.

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The Month's News in Brief

News Briefs

This year's British Association programme includes a number of papers to the Engineering Section on automation. Among the speakers will be Mr. A. J. Young of I.C.I. (Automatic control of processes) and Dr. D. Taylor of Harwell (Atomic energy and automation). The special automation sessions are arranged for September 3 and 4. The chemists will be hearing lectures covering such topics as titanium manufacture (Dr. James Taylor of I.C.I.), very high-temperature reactions (Prof. George Porter, Sheffield University) and anti-oxidants in the food, oil and rubber industries. The meeting is being held in Sheffield from August 29 to September 5.

An important and unusual inauguration ceremony was held on August 1, at the headquarters of the British Oxygen Co., Bridgewater House, London. Major the Rt. Hon. Gwilym Lloyd-George, Home Secretary and Minister of Welsh Affairs, started Britain's first tonnage oxygen plant, which will service the Steel Company of Wales works at Margam, near Swansea, by pressing a button. The plant is the first of five which are being constructed by B.O.C. to service individual iron and steel works in many parts of the country. The total cost of the initial schemes is estimated at over £3 million, of which the complete Margam project will cost £1 million. Those present at the ceremony were able to watch the starting up and also to make a complete "tour" of the plant by means of a special closed-circuit television link which gave a good picture over the 200 miles separating Margam and London.

Work has now commenced on a new £½ m. Gloucester factory for Permali Ltd. It will occupy a 6½-acre site opposite the existing premises in Bristol Road and should be completed by the end of next year.

Frasers announce that, in addition to the contract recently awarded by the Shell Company of South Africa for a large-scale lube oil blending and packing plant at Durban, they have now been commissioned to engineer and erect a complete grease manufacturing plant alongside. Frasers South African associates, Fraser and Chalmers Ltd., will play an important part in controlling local operations.

Albright & Wilson announce the signing of a preliminary Letter of Intent which sets out the basis of negotiations for a proposed amalgamation of their American subsidiary, Oldbury Electro-Chemical Company of Niagara Falls, N.Y., with Hooker Electrochemical Company, also of Niagara Falls, N.Y.

The I.C.I. contingent to the Duke of Edinburgh's Study Conference on Human Problems in Industry held at Oxford. This photo was taken on the roof of Imperial Chemical House. Back row, standing, left to right: Mr. O. J. Coffey, melter, Titanium Plant, Metals Division; Mr. W. J. P. M. Garnett, Central Labour Department; Mr. R. L. Bewick, Southern Region Sales Office; Mr. M. J. S. Clapham, managing director, Metals Division; Mr. Y. Khan, accountant, Head Office, I.C.I. (Pakistan); Mr. E. T. Grint, Central Labour Department; Mr. J. P. Wapenaar, chief superintendent, Ammonia Synthesis Department, A.E. and C.I., Modderfontein; Mr. W. Heath, bag loader, Billingham Division; Mr. S. A. G. Anderson, assistant chief superintendent, Nitric Acid Plant, A.E. and C.I., Modderfontein; Mr. R. F. Maddison, chief industrial officer, I.C.I.A.N.Z. Ltd.; Mr. S. P. Leigh, overseas controller, I.C.I. Head Office; Mr. W. E. Garrett, fitter, Prudhoe Works, Billingham Division; Mr. W. S. Bristowe, head of I.C.I. Central Staff Department; Mr. E. A. Bingen, overseas director, Main Board, I.C.I. Ltd.; Mr. L. Hemsworth, commercial studies manager, Development Department, C.I.L. Montreal. Sitting, left to right: Mr. R. Donaldson, nitroglycerine processman, Nobel Division; Mr. R. A. Banks, personnel director, Main Board, I.C.I.; Mr. S. J. Gilbert, process worker, Botany Factory, I.C.I.A.N.Z. Ltd.; Mr. C. R. Prichard, overseas director, Main Board, I.C.I. Ltd.

The North Thames Gas Board has awarded a contract to Humphreys & Glasgow Ltd. for the installation of four refinery gas reforming plants at Romford in Essex.

Mr. Fison, in his Annual Report for the year ending June 30, 1955, referred to the restraint which the Company was exercising in its price policy. The Company was not passing on to the farmer all the extra costs which were being incurred. The Board of Directors took the view that it was the Company's duty to assist Agriculture in this way and share the farmers' difficulties.

The formation of a new company (Efco-Edwards Vacuum Metallurgy Ltd.) is jointly announced by Edwards High Vacuum Ltd. and the Electric Furnace Company Ltd. These two companies are leading specialists in high vacuum equipment and electric furnace installations, respectively.

Fertilisers & Chemicals, Travancore Ltd., have just signed a contract with Chemiebau Dr. A. Zieren G.m.b.H., for the construction of a new sulphuric acid contact plant. This plant will utilise elemental sulphur for the production of 160 tons of monohydrate per day. The new plant, together with two existing units, makes F.A.C.T. the largest manufacturer of sulphuric acid in India.

The telephone number of Aero Research Limited, Duxford, Cambridge, has been changed to Sawston 2121. The Telex number is 10-101.

I.C.I. announced late July that the company is to make no further increase in home trade prices of a wide range of its products until June 30 next year.

A special shareholders meeting will be held early in September by the former German chemical trust I.G. Farben, now in liquidation. The meeting will seek approval of the company's offer to pay DM.30m. (about £2.5m.) compensation to its one-time "slave workers."

Petrochemicals, a subsidiary of Shell Chemical, has acquired Erinoid's 40% holding in Styrene Products. Mr. L. H. Williams will remain as chairman and Mr. P. C. Chaumeton as managing director of Styrene Products.

Atomics

Further capital outlays of $190m. will be required to finance the Canadian uranium mining companies, whose applications for contracts for sale of concentrates are now in process, it was recently estimated by Mr.

BC7 306 for further information

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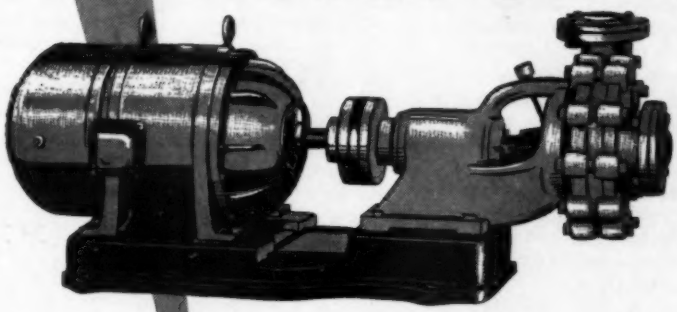

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Bennett, president of Atomic Energy of Canada.

Mr. F. Osborne, Australian Minister of Customs, announced the lifting of export control over about 20 main items in accordance with the Government's policy of relaxing export restrictions wherever possible. As a result of this, nuclear reactor materials and radioactive minerals, including uranium, can be exported only with the approval of the Australian Atomic Energy Commission.

One result of Franco-American co-operation on the peaceful uses of atomic energy will be that France will receive 40 kilogrammes (about 88 lb.) of enriched uranium U-235.

A non-profit-making company, the Atomic Reactor Financing Company, is to be founded to operate the Karlsruhe (Germany) 11-megawatt research reactor.

Two broadsheets on the production and industrial uses of atomic energy, with an assessment of its future contribution to national economy, are published by P.E.P. (Political and Economic Planning), price 2s. 6d. each.

Czechoslovakia has begun preparatory work on an atomic reactor (the country's first), according to Tass, the Soviet News Agency.

People

Mr. A. Shavitsky arrived last month from Australia and succeeded **Mr. W. Ives** as chief scientific liaison officer (Australia) at the B.C.S.O., Africa House, Kingsway, London, W.C.2, on July 2.

Mr. A. A. H. Douglas is relinquishing, at his own request, his appointment as director and general manager of the Distington Engineering Company, a subsidiary of the United Steel Companies. **Mr. G. N. F. Wingate**, at present works manager (services) at the Steel Peech and Tozer branch of the United Steel Companies, succeeded Mr. Douglas on August 1.

Mr. Harry West has been appointed managing director of the A.E.I.-John Thompson Nuclear Energy Company. A director and chief electrical engineer of Metropolitan-Vickers, Mr. West was associated with the A.E.I.-John Thompson Industrial Nuclear Energy Group from its inception.

The Duke of Edinburgh, as president, presented the gold Albert Medal of the Royal Society of Arts, for 1956, to **Sir Henry Dale** for eminent service to science, particularly physiology. The presentation took place at the Society's headquarters in John Adam Street, W.C., during July.

The following appointments are announced by Borax Consolidated Ltd., and took effect from July 4, 1956. **Mr. N. C. Pearson**, assistant managing director; **Mr. C. M. Houlton**, general sales manager; and **Mr. A. G. H. Bell**, assistant sales manager. **Mr. F. A. Lesser** as managing director will continue to devote his attention to finance, accounts and questions of broad policy.

Mr. A. H. Giles, formerly of Heat Exchangers Ltd., and Superheater Company Ltd., has now joined Heat Transfer Ltd., as managing director.

At a meeting of the Council of the Institute of Industrial Administration, held in Management House on July 13, the Bowie Medal for 1956 was presented to **Mr. E. F. L. Brech**, consultant, author and lecturer on management subjects. The award commemorates the work carried out for the Institute by the late **Dr. James Bowie**, pioneer of management education in Britain.

Mr. G. H. Greenhalgh joined D.S.I.R. in July as Scientific Attaché in Scandinavia. He is being loaned to D.S.I.R. by the Atomic Energy Authority's Research Establishment at Harwell and he will take up his duties in Stockholm in August after briefing in this country. Mr. Greenhalgh succeeds **Mr. R. G. Silversides,** who has returned to D.S.I.R. Headquarters.

Dr. T. Vickerstaff has been appointed chief colourist of I.C.I. Dyestuffs Division, at Blackley, Manchester, in succession to **Mr. G. O. Mitchell**, who has retired,

Mr. G. A. Dummett was elected to the Board of Directors of The A.P.V. Company Ltd. at the Annual General Meeting held on July 25, 1956.

On August 29, **Lord Halifax**, the Chancellor of Sheffield University, will confer honorary degrees on **Sir Raymond Priestley**, **Sir George Paget Thomson** and **Sir Charles Goodeve** at a Congregation in the Sheffield City Hall. Sir Raymond Priestley, president of the British Association for the Advancement of Science, who is to lecture on "Twentieth Century Man Against Antarctica" at the subsequent inaugural meeting, will receive the honorary degree of Doctor of Laws. Sir George Paget Thomson, Master of Corpus Christi College, Cambridge, and Sir Charles Goodeve, director of the British Iron and Steel Research Association, are to receive the honorary degree of Doctor of Science. Both are sectional presidents for the meeting, Sir George for the mathematics and physics section and Sir Charles for chemistry.

Coming Events

The Convention of Chemical Sciences, 1956, will take place in Paris from November 18 to December 3 next, at the same time as the IVth Salon de la Chimie-Caoutchouc-Matières Plastiques. This will include several meetings of particular importance, notably the XXIXth International Congress of Industrial Chemistry, the 1st European Congress of Corrosion, the European Conference of Chemical Engineering and the Paris Technical Meetings.

The IX International Congress of Applied Mechanics will be held in the University of Brussels from September 5 to 13, 1956.

The Third International Congress on High Speed Photography (September 10 to 15. 1956) will be held at the Government Offices, Horseguards Avenue.

The 48 Annual Autumn Meeting of the Institute of Metals is to be held at Stuttgart, Germany, from September 17 to 25, 1956.

A Symposium on "Extruded Rubbers and Plastics" will be held in the National College of Rubber Technology, Holloway Road, London, N.7, on October 30 to 31, 1956.

October: The 38th National Metal Exposition and Congress of the American Society for Metals will take place in Cleveland from 8th to 12th October, 1956.

New Publications

The British Standards Institution has recently issued a British Standard "Dimensioning system and terminology for industrial temperature-detecting elements and pockets." Copies of this (B.S. 2765) may be obtained from the British Standards Institution, British Standards House, 2 Park Street, London, W.1. Price 2s. 6d.

The Nichols Herreshoff Furnace, a 4 pp. leaflet on the use of this type of furnace may be obtained from Huntington, Heberlein & Co. Ltd., Simon House, 28-29 Dover Street, London, W.1.

"An industry within industry," is the title of an attractively produced booklet which details "the place and purpose of Johnson, Matthey." (Hatton Garden, London, E.C.1.)

"Invoicing Methods," published by the British Institute of Management, 8 Hill Street, London, W.1, at 21s., is reported as the first complete guide to methods of invoicing in this country —if not the world.

I.C.I. have recently published two booklets on Terylene. One, "Terylene in industry," gives, as the title suggests, some of the present uses for the fibre in industry and discusses some of its future applications. The other is a buyers' guide—industrial version—and lists manufacturers and merchants employing Terylene.